Statement of Authentication

I Yahya Elhallak confirm that this thesis contains no material that has been accepted for the award of any other degree or diploma and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, expect when due reference is made in the text of this thesis.

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The Use of Cavity Barriers to Mitigate External Fire Spread in Multi-Storey Buildings

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ABSTRACT

This report outlines a study on the effectiveness of cavity barriers in multi-story buildings. The function of a cavity barrier is to provide a fire blocker in the cavities located within the external walls of multi-story buildings, which assist to mitigate vertical fire spread. The literature review conducted within this report describes what building façades, a cavity and cavity barriers are. The main goal of the research conducted is to determine if the installation of cavity barriers is effective in stopping vertical fire spread on a building that incorporates combustible building elements along the facade, such as aluminium composite panels (ACP) with a combustible polymer core. Previous studies on cavity fires were assessed in this literature review, it was found that the width of the cavity impacts on fire growth within a cavity fire, it was also noted that a fire within a cavity is prone to rapid fire spread of up to 5-10 times faster than an external fire, this is due to the air flow and configuration of the cavity, known as the chimney effect. The National Construction Code (NCC) of Australia does not allow any combustible elements to be used on the external wall of a building; this requirement was supported with the introduction of a product ban introduced in 2018. The Commissioner of NSW Fair-trading placed a ban on building products with more than 30% combustible matter. It has become evident that many buildings all over Australia have been identified with combustible cladding on their facades, to which the costs of replacing can be severe, and as such many building owners are looking to retain the cladding. The aim of this study is to show that the installation of cavity barriers can mitigate vertical fire spread on buildings.

A comparative study was conducted on a building that has cavity barrier and on a building that does not have any cavity barriers, where all other components are consistent to determine if there is a major difference with the fire spread, this is explained in Chapter IV, and will be simulated using Fire Dynamics Simulator (FDS) modelling.

The data and results will be analysed to assess the hypothesis of this report, which is installing cavity barriers in Ventilated Façade (VF) systems will greatly improve the fire performance of a building and mitigate external and vertical fire spread.

ACKNOWLEDGMENTS

I would like to start by thanking my supervisor, Dr Yaping He and my Co-Supervisor Sameera Wijesiri Pathirana of the School of Computing, Engineering and Mathematics at Western Sydney University, for his support and advice throughout the process of undertaking this thesis. The guidance and information provided was extremely valuable and helped shape its contents.

Secondly if it wasn’t for the guidance and tutoring of my Employer Dr, Amer Magrabi of Lote Consulting, I would not have been able to produce an informative document. Through his guidance and supply of relevant information I was able to think of different ways in which this thesis answers the overarching question of cavity barrier fire protection.

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GlOSSARY

- **Attachment –** A building element that is used as an attachment to a building façade, for decorative and or weatherproofing reasons.
- **BCA –** Building Code of Australia
- **Cavity -** A cavity wall or cavity is a type of wall that has a hollow center, They can be described as consisting of two "skins" separated by a hollow space
- **Cavity Barrier –** A fire blocking material used within cavities to provide vertical fire stopping
- **Cladding** – A type of attachment to a building façade, generally consisting of aluminium composite panels (ACP)
- **Combustible –** Means a material that is not mentioned in the BCA Clause C1.9 or is deemed to be combustible under AS 1530.1:1994.
- **External Wall –** Defined in the BCA Volume One 2019 as an outer wall of a building which is not a common wall.
- **Façade –** The exterior face of a building exposed to weather conditions.
- **FRL –** Refers to Fire Resistance Level as defined in the BCA, with respect to Structural adequacy, Integrity and Insulation Criteria.
- **NCC –** National Construction Code
- **Non-combustible –** Means a material referenced in the BCA Clause C1.9 or is deemed non-combustible under AS 1530.1:1994.

1 CHAPTER I: INTRODUCTION

This document refers to the study on cavity barrier installation in multistorey buildings and comprises the following components, Chapter 1 is the introduction which formulates this section and provides a general overview of this research paper, Chapter 2 is the Literature Review comprising different sections such as topic background, introduction to combustible facades and cavity barriers. Chapter 3 described the methodology used to assess the hypothesis of this report while Chapter 4 provides the results taken from the computer simulations which are discussed in the discussion section in Chapter 5.

The overall intent of this research paper is to show how the installation of cavity barriers will help mitigate vertical fire spread in multi-storey buildings. The National Construction Code (NCC) states that a building must be constructed to comply with Performance Requirement CP2 for it to comply with the Deemed-to-Satisfy (DtS) Provisions, in terms of fire spread to and from buildings. (ABCB, 2019)

Currently the world is in the development of many high-rise buildings, a lot of them with a combustible cladding façade which incorporates unprotected cavities. “Exterior cladding is prone to rot and fungus and the common way to prevent this is by natural vertical flow of air in gaps behind the outer rainscreen.” (Geir, 2013) This provides a path for fast and hidden fire spread, which may extend to large inaccessible areas and internally to the upper levels of the building before breaking through the cladding.

With the consideration given to air ventilation and fire risks caused by cavities, this research paper will provide guidance on the following:

- How will the use of cavity barriers and perimeter fire stopping mitigate external fire spread?
- Does restricting an external façade fire to each floor mitigate the spread of fire from the façade to the internal parts of the building?
- Do the material utilised within the cavity (i.e. sarking, insulation and fixings) impact on the growth and speed at which the flame spreads vertically up the façade and within the cavity?

1.1 Main Objectives of Research

As stated above, the aim of this research paper is to determine the effectiveness of cavity barriers on vertical fire spread via the building's external walls of various texture with cavity.

Such research can potentially provide Fire Engineers a means to justify the retention of combustible building elements on the façade of buildings, where otherwise not permitted by DtS provisions of the construction code. As such the following points summarise the main objectives of this thesis.

- To establish the behaviour of fires and flames on the external façade and within the cavity of the external walls;
- To identify how effective the installation of cavity barriers is to mitigate vertical fire spread through building façades and cavities; and
- To determine if cavities barriers will aid in the retention of combustible building elements, where otherwise not permitted under DtS provision.

2 CHAPTER II: LITERATURE REVIEW

2.1 Background

It is important to note that façade fires have become more prolific globally in recent times. Since the Grenfell Tower fire that occurred in London on June 2017 and a number of subsequent close calls all over the world including the Lacrosse fire that occurred in Melbourne on November 2014, it has become apparent that the quality of building materials used for external facades shall be reviewed. (SFS, 2019)

Based on the recent events that have been occurring throughout the world in relation to building fires, it was determined the risk assessment of buildings should be viewed as a holistic exercise, in looking at all facets of the building design, construction and occupancy that can contribute to overall fire safety. (Barnett, 2020)

Furthermore, these recent fires have resulted in Federal and State Governments inquiring into the potential exposure for buildings in relation to non-conforming and non-compliant building products, focusing to exposure caused by Aluminium Composite Panels. (Sullivan, 2017)

The portions of NCC Deemed-to-Satisfy (DtS) provisions relevant to passive protection against external fire spread are identified below:

- NCC Clause C1.9 (Non-combustible Building Elements)
- NCC Clause C1.10 (Fire Hazard Properties)
- NCC Specification C1.13 (Cavity Barriers for Fire-protected Timber)
- NCC C2.6 (Vertical Separation of Openings in External Walls) (NCC Volume 1, 2019)

The above sections of the NCC set out some of the minimum fire safety requirements a building shall meet for compliance and mitigation of fire spread, loss of life and property damage.

NCC Clause C1.9 and C2.6 are most relevant to external fire spread, as their intent is as follows:

- NCC C1.9 - to specify the non-combustibility for building elements and to permit the use of certain materials that are known to provide acceptable levels of fire safety where an element is required to be non-combustible. (ABCB, 2019) and
- NCC C2.6 – to minimise the risk of fire spreading from one floor to another via openings in external walls in buildings of Type A construction. (Guide to NCC Volume 1, 2019);

In light of the above and recent cladding fires, the Commissioner of Fair Trading, Department of Finance, Services and Innovation, released a NSW product ban on all cladding materials installed on Type A and B buildings that have a combustibility of 30% or more, this ban was put into effect on 15 August 2018. (Aluminium composite panel ban, 2020)

As a referenced term *combustible* with regards to the National Construction Code 2019 is defined as a material that does not pass the AS 1530.1:1994 test. (NCC Volume 1, 2019 Definitions)

There are two (2) main aspects to external fire spread, firstly the construction material, which is covered under NCC Clause C1.9 as mentioned above, and the second is vertical fire spread through openings which is covered under NCC Clause C2.6. However, fire behaviour is also influenced by ventilation conditions. With reference to Figure 1 another major aspect of cladding fires that has been neglected is the cavity that is present due to the nature of its installation and fixing method. The cavity is the space between the building's façade and the buildings internal wall. The cavity creates a channel for fire to spread and acts as a chimney. Hence the installation cavity barriers will significantly mitigate external fire spread and the vertical fire spread from floor to floor.

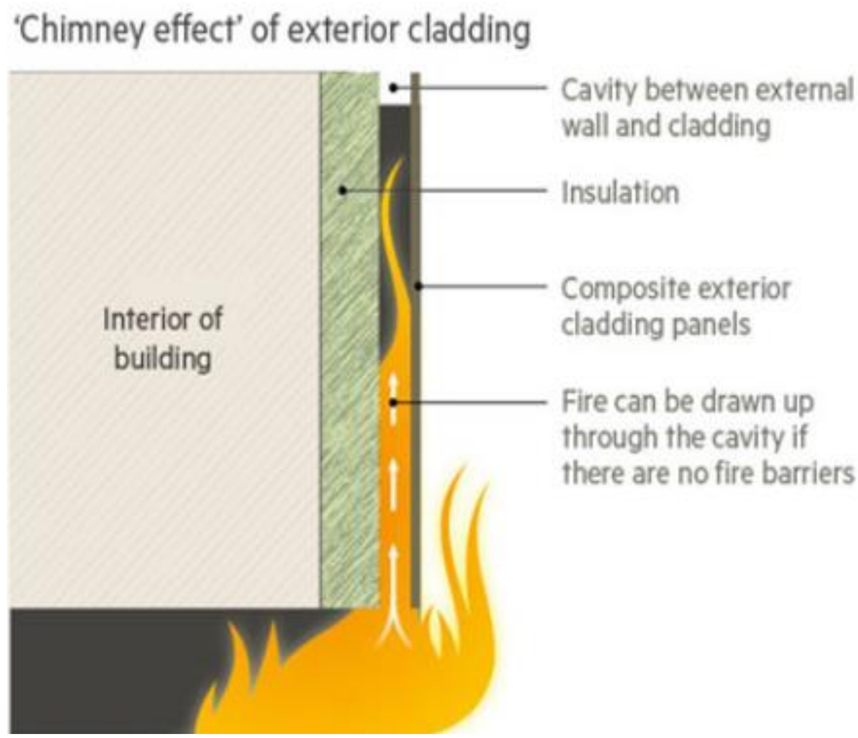


Figure 1 – A building façade system with a cavity as a possible route for fire spread.

As mentioned above, the use of cavity barriers and perimeter fire stopping within the cavities of multistory buildings has not yet been mandated in the National Construction Code (NCC), with the exception of Specification C1.13 where cavity barriers are required in certain locations where fire protected timber construction is used. (NCC Volume 1, 2019 Spec C1.13)

It is to be noted that in the United Arab Emirates (AUE), the use of cavity barriers and perimeter fire stopping is a requirement, specifying the FRL requirements as well the installation detail of these systems.

This research topic will look at how the installation of approved cavity barriers and perimeter fire stopping impacts on the behavior of fire and smoke spread via the external walls and cavity on multistory buildings and hopes to provide insight on how we can use these systems to better the fire performance of multistory buildings.

This research can assist Fire Engineers in addressing a building with combustible cladding, if it is deemed acceptable to be retained based on the installation of cavity barriers. By showing how the cavity barrier reacts with external cladding fires, and how much it helps mitigate fire spread, the aim of such fire safety measures can be extended to justify the retention of certain combustible external building elements, which will benefit the building owners greatly.

2.2 Introduction to Combustible Façade and Cavity Barriers

2.2.1 Combustible Cladding

Combustible facades are becoming more and more prominent on multistory buildings around the world as they provide an aesthetic appeal for a relatively cheap cost. A façade is the exterior face of the building generally consisting of elements to provide weather proofing to the internal portions of the building as well as provide a pleasant aesthetic design, as shown below in Figure 2. The issues with aluminum composite panels primarily relate to multi-story buildings and the potential for rapid vertical fire spread via the façade, cavity or external wall, where inappropriate products have been used. (McNally, 2015).

Figure 2 – Photo showing external combustible façade of a building used as a weatherproof and decorative lining

Aluminium Composite Panels (ACP) are sandwich-type panels consisting of two aluminium faces and a core material, typically being polyethylene, mineral-based material or a combination of both. Panel thickness tpically range between between 3 – 5 mm, however some other forms of cladding consist of insulated composite panels which can be of thickness of more than 100 mm, these panels are generally used as an external wall and not an attachement as well as used internally as storage separating walls such as fridge panels. As a visual representation refer to Figure 3 below, showing the different layers of composite panels and how the combustible internal core melts upon exposure to heat, it is to be noted that the melting point of aluminium is aproximately 600 degrees Celcius, at which point the combustible core is exposed and prone to rapid fire spread. (Chen, et al., 2019)

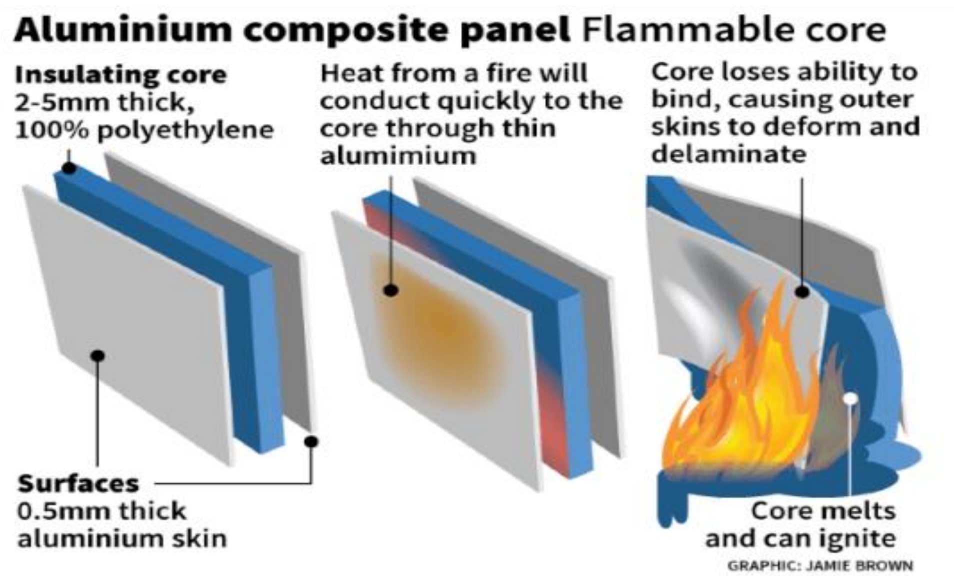


Figure 3 – Figure showing ACP make-up and how fire impacts on its performance (al, 2020)

The Insurance Council of Australia have categorized cladding into four (4) categories from highest fir risk to least fire risk, with reference to Table 1, a summary of this categorization is shown.

Table 1 – ICA categorization of different types of combustible cladding

Category	Polymer % Range	Polymer %	Inert Filler
A	30-100% Polymer and 0-70% inert materials	30-100%	0-70%
B	8-29% Polymer and 71-92% inert materials	8-29%	71-92%

Category	Polymer % Range	Polymer %	Inert Filler
C	1-7% Polymer and 93-99% inert materials	1-7%	93-99%
D	0% Polymer and 100% inert materials or deemed non-combustible by the NCC	0%	100%

The main objective of this categorization is to help identify the level of risk a building with combustible cladding is presented with and assist with the risk assessment and rectification measures required to maintain a suitable level of risk, in particular it is important for building Insurers to ensure the buildings they are associated with are provided with a low fire risk, to assess the risk posed with ensuring the subject buildings and help determine the increase in costs to the premium.

Below is a description of the breakdown provided in Table 1 above.

1. 30 – 100% Polymer and 0 – 70% Inert filler:

Inert materials are considered those that do not contribute to combustion.

ACP's in this category typically have close to 100% organic polymer in their core and were identified by most manufacturers as PE (Polyethylene) core. Some core binders are polymers other than PE.

2. 8-29% Organic Polymer and 71-92% inert:

Typically identified by ACP manufacturers as fr, FR, Plus or rated Class B per EN 13501 and typically have around 30% organic polymer in the core however some State Regulations limit the PE content to less than 30% for this category

3. 1-7% Organic Polymer and 93-99% inert:

These are considered as having very limited combustibility. Testing to EN 13501 and obtaining class A2 is a valid alternative.

4. 0% Organic Polymer and 100% inert:

Typically, panels tested or deemed non-combustible by the building code (NCC). These could be aluminum skins with low adhesive aluminum honeycomb cores, or with a compressed phenolic core, compressed fiber cement core or even compressed fibre cement panel. Steel panels with calcium silicate or similar core. (Sullivan, 2019)

2.2.2 NCC Compliance

As discussed earlier, the relevant NCC (ABCB, 2019) Clauses relevant to external vertical fire spread are Clause C1.9 and C2.6, the main intent of the requirements set out in these clauses is to achieve compliance with Performance Requirement CP2, which refers to fire spread, the Guide to the NCC 2019 (ABCB, 2019) states that Performance Requirement CP2 “deals with the spread of fire both within the building and between buildings, and which does not only result from the structural failure of a building element.”

Furthermore the Guide to NCC 2019 states that the intent of Clause C1.9 is “to specify the non-combustibility for building elements and to permit the use of certain materials that are known to provide acceptable levels of fire safety where an element is required to be non-combustible.” This is important when specifying a cavity barrier system, as it comprises part of the external wall system which is required to be entirely non-combustible, in which case the cavity barrier not only has to provide a fire resistance but must also be non-combustible as per AS 1530.1.

With reference to Clause C2.6, the Guide to NCC 2019 states that the intent is to “minimize the risk of fire spreading from one floor to another via openings in external walls in buildings of Type A construction”. The main purpose of a cavity barrier is to prevent fire from spreading vertically via the cavity of the external walls of the building as shown below in Figure 4. It is important to note that in many cases with curtain wall construction, to provide the required vertical spandrel separation a cavity barrier will be needed but is sometimes missed during the construction and design phases of a development.

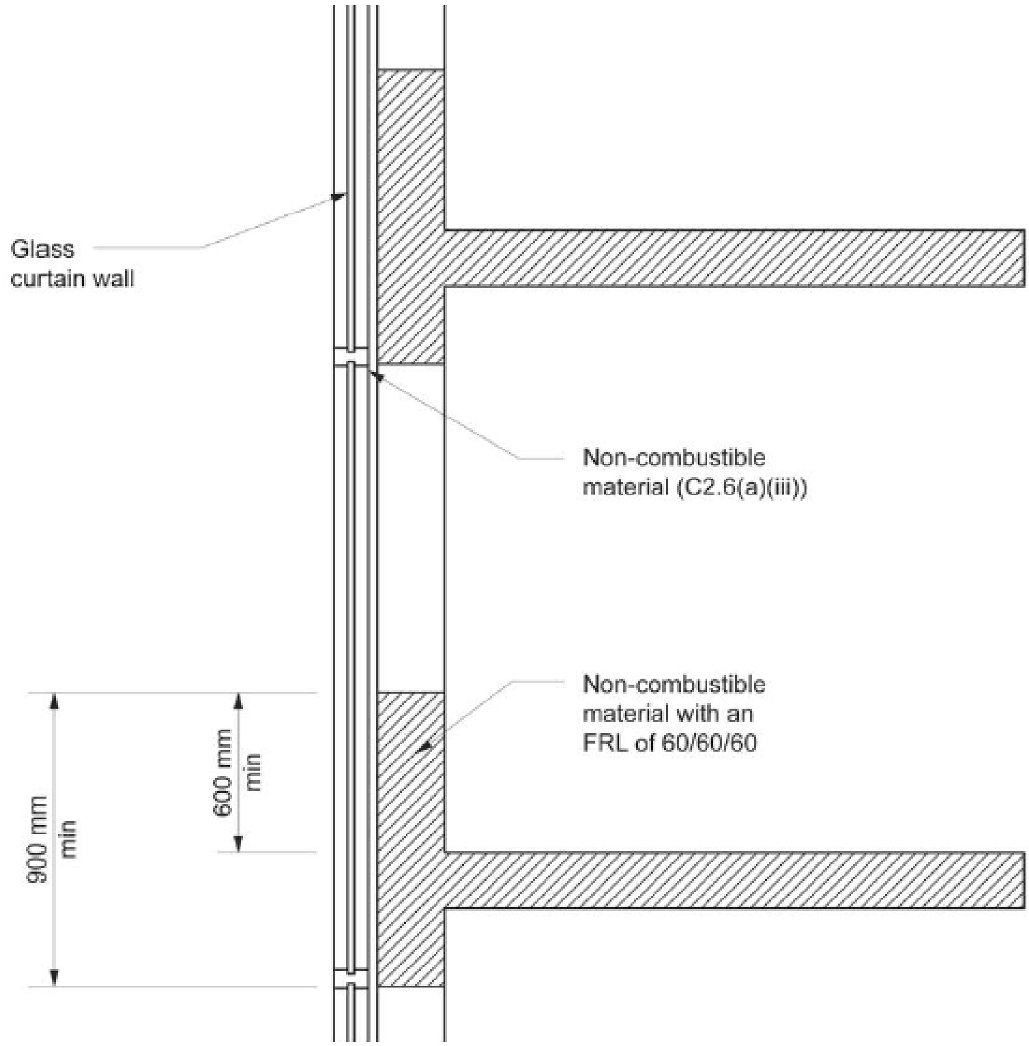


Figure 4 – Extract of the Guide to NCC 2019 from Clause C2.6, showing detail of vertical fire separation along a curtain glazed wall with a cavity

In the case of NCC DtS Provisions, the installation of the cavity barrier system will help achieve compliance with Performance Requirement CP2.

2.2.3 Cavity Barriers

Cavities:

To first understand what cavity barriers are and what their main function is it is important to know what cavities (building cavities) actually are. "A cavity wall or cavity is a type of wall that has a hollow center. They can be described as consisting of two "skins" separated by a hollow space (cavity)." (Oxford, 2009) The skins typically consist of the internal wall and the external wall, in the case of multi-story high-rise buildings it is generally attached cladding for decorative and weatherproofing purposes, whilst traditionally cavities were only constructed or found in brick or masonry buildings.

With reference to Figure 5, different types of cavities used on typical buildings are shown. The main purpose or advantage of cavities is their contribution to thermal comfort and energy saving as well as elimination of condensation on the inside of the façade wall:

- **Thermal contribution**: this is generally provided as a result of fitting insulation in the cavity eliminating thermal bridges in any part of the façade, thereby preventing the loss of heat to the exterior in winter and absorbing heat in summer; and
- **Elimination of condensation on the internal face of the façade wall**: The pressure difference between the air in the cavity and outside leads to the creation of an airflow known as the "chimney effect", which eliminates humidity in wet conditions and prevents condensation. However in terms of fire safety, the chimney effect poses a risk, because the ventilated cavity may provide a pathway for the fire to spread quickly. (Giraldo, et al., 2013), this study is discussed in Section 2.5.

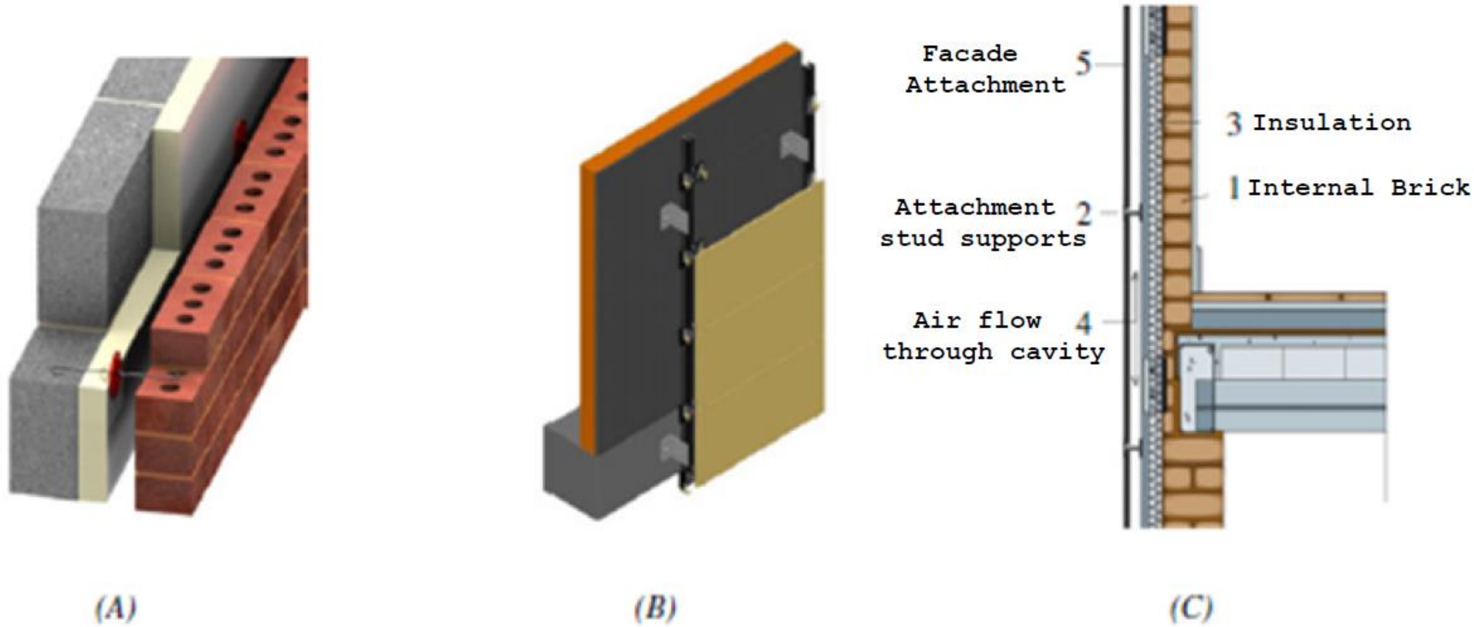


Figure 5 – Façade cavity systems (A) Cavity wall (B) Ventilated façade (C) elements of ventilated façade (Giraldo, et al., 2013)

As mentioned above, the presence of cavities on the external facades of high-rise buildings poses a fire risk as it acts as a wind tunnel from the lowest level to the top of the building. The main concern in this situation relates to buildings with combustible façade such as (ACP cladding), which increases the chances of rapid vertical fire spread and fire spread from the lower levels of the building to the upper levels, as such the introduction cavity barriers (fire stops) is proposed to mitigate this concern.

Cavity Barrier:

This study will focus on the fire stopping properties cavity barriers and perimeter fire stopping provides on multi-story high-rise buildings and will aim to determine if the advantages provided by such fire stopping measures outweighs the requirement to remove all the combustible elements found on the external walls of Type A and B buildings.

When referring to cavity barriers there are two (2) systems that are outlined, this depends on the construction method of the external wall and building façade, these two (2) systems are cavity barriers and perimeter fire stopping. It is to be noted that both systems are a form of cavity barriers and in many instances the same tested product can be used to get the desired fire resistance. With reference to Figure 6, the difference between perimeter fire stopping and cavity barriers is shown. The main difference between the two is the construction of the external walls.

Perimeter fire stopping is applied where the buildings external wall does not provide a fire resistance level and is attached to the edge of the slab, in this case a barrier is provided between the slap edge and the fire resisting portion of the external wall (providing the spandrel separation required under NCC Clause C2.6) as shown in red, creating the vertical floor to floor separation. It is to be noted that this configuration does noes contain a cavity, as such this research paper will focus on the cavity barrier fire stopping system instead.

Cavity barriers as shown in Figure 6 (b), consist of a barrier sandwiched in the cavity of the building, (i.e. installed in-between the buildings external wall and the façade attachment), in this instance the internal portions of the external wall is providing the fire resistance however the cavity introduced as a result of the façade attachment is an open vertical gap which is sealed off with cavity barriers at each level, the cavity barrier is generally installed at the slab edge, providing the floor to floor separation.

It is important to note that for both perimeter fire stopping and cavity barriers, the same products can be used to achieve the required fire resistance levels.

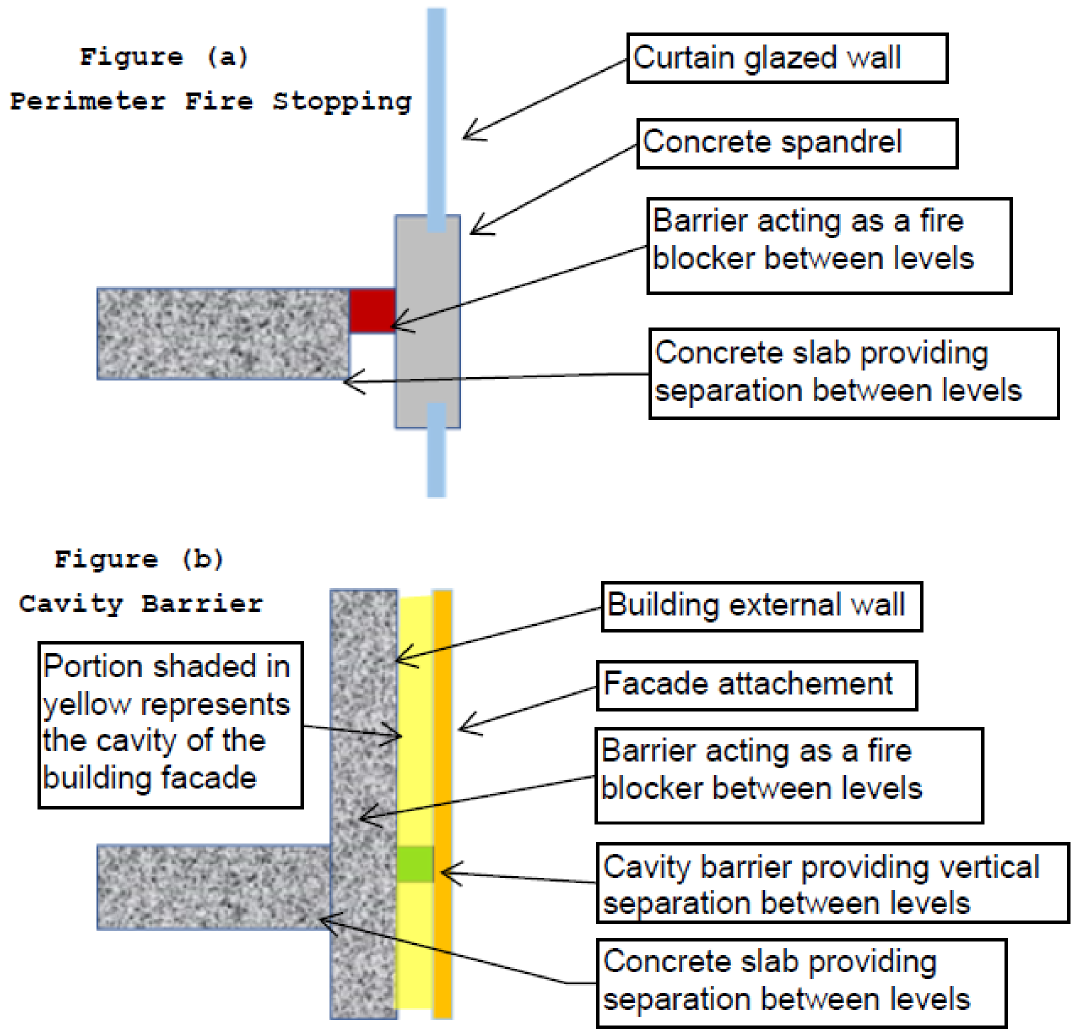


Figure 6 – Caption showing elements of (a) perimeter fire stopping installation; and (b) cavity barrier installation

2.2.4 Types of Cavity Barriers

There are two (2) main types of cavity barriers provided in the market:

- Fire blockers; and
- Intumescent based strips.

The most commonly used products are the fire blockers, this is representative of the illustration shown above in Figure 5, the intent of this type of system is to provide a permanent seal between floors by providing a fire resisting material between the concrete slab edge and extending it all the way to the façade attachment, leaving no gaps for air and the like.

Figure 7 – Rockwool based product providing fire separation between floors by sealing cavity completely

The second type is an intumescent based product which reacts with the heat of the fire and expands to fill the cavity so that the fire does not spread vertically up the building cavity, the advantages of this system is that it provides a small opening for the travel of air and the installation of sarking to which the issue of condensation will be resolved.

The particular product shown below, (Bossfire Rainscreen) typically activates when the temperature of the product reaches 150 degrees C, once it activates it will expand to fill the cavity entirely stopping the fire from spreading vertically up the building.

Figure 8 – Rockwool based product with intumescent strip at the end which expands upon reaction with heat (approx. 150 degrees C) to seal the cavity

2.3 Building Code Requirements - Combustible Elements & Cavity Barrier Installation

2.3.1 BCA Requirements of External Combustible Building Facades

In 2003 the Building Code of Australia (BCA) 1996 Volume 1 Amendment 13, introduced Clause C1.12 which allowed the use of bonded laminate materials on Type A and Type B construction, considering that each layer is non-combustible. This clause however did not consider the combustibility of the sarking and insulation products located behind the cladding. Combustibility in the context of the BCA is defined as "*material deemed combustible or non-combustible as determined by AS 1530.1*".

Post Lacrosse and Grenfell, changes to the requirements of the BCA were implemented. In May 2018, BCA 2016 Volume 1 Amendment 1 was brought into effect which introduced Clause C1.9. This prohibited the use of combustible materials in "*external* *walls and common walls, including all components incorporated in them including the façade covering, framing and insulation*".

Some of the following factors which are not currently addressed in the NCC shall also be taken into consideration to improve life safety in terms of façade fire in a building:

- Installation methods and the resultant debris that may be associated with a fire; and
- The installation of cavity barriers in high-rise buildings.

The above factors will contribute to the effects of a fire and what measures shall be put into place to combat the associated risks.

The NSW government has released the State Environmental Planning Policy Amendment (2018), which came into effect as of 22nd October 2018 as a result of the NSW building product ban which was introduced by the NSW fair trading commissioner on the 10th of August 2018. (NSW Fair Trading, 2018)

As shown in Appendix A, the NSW ban is set in place to prohibit the use of any cladding with more than 30 % combustible matter, and as such the FRNSW, Council and other agencies are working together to assess existing buildings with cladding and determine through a fire engineering assessment, the level of risk and whether or not they will need replacing, rectifying or can remain in place. A 10-point plan was devised to deal with buildings of certain classes that are furnished with cladding. The main points of the plan are:

- Identification of buildings with the hazardous material present;
- Education for owners of affected buildings;
- Creation of a taskforce to enforce the reform;
- Greater supervision by fire safety engineers into works authorised by building certifiers; and

- More frequent and stringent auditing by local government.

It is to be noted that BCA Clause C1.9 does not allow the use of any combustible elements in the buildings external walls (Type A and B) as such, the ban does not mean that if the cladding installed on the building is less than 30% PE content it is Deemed-to-Satisfy (DtS), this will only be the case if the external wall and components incorporated within are deemed non-compliant as per AS 1530.1. (ABCB, 2019)

Where Performance Solutions are adopted to address the use of an external cladding product that does not satisfy the BCA DtS Provisions, the product is to satisfactorily demonstrate to the Authority Having Jurisdiction (AHJ) that the design will satisfy the relevant BCA Performance Requirements primarily Performance Requirement, CP2(a)(iv), which requires the external cladding product to demonstrate its capacity to avoid the spread of fire via the façade of a building to meet the fire resistance requirements of the BCA.

Verification Method CV3 includes a new testing standard AS 5113 for testing external wall assemblies for fire spread and additional fire safety measures such as enhanced sprinkler system, cavity breaks and the like as a condition of using the AS 5113 tested wall assembly. (ABCB, 2019)

2.3.2 Requirements of Cavity Barrier Installation

The National Construction Code of Australia (ABCB, 2019) does not prescribe the installation of cavity barriers, as such is currently a performance based system used for the upgrade of a buildings passive fire safety system, it is to be noted that with the introduction of Verification Method CV3, a building external wall to achieve an EW (External Wall) classification must be provided with cavity barriers, however this is a performance based design on a system that is not Deemed-to-Satisfy. With reference to Figure 9, the requirements set out in CV3 are provided.

CV3 Fire spread via external walls

Compliance with CP2 to avoid the spread of fire via the *external wall* of a building is verified when—

(a) compliance with CP2(a)(iii) to avoid the spread of fire between buildings, where applicable, is verified in accordance with CV1 or CV2, as appropriate; and

(b) the *external wall* system—

- (i) has been tested for external wall (EW) performance in accordance with AS 5113; and
- (ii) has achieved the classification EW; and
- (iii) if containing a cavity, incorporates cavity barriers and these cavity barriers have been included in the test performed under (i) at the perimeter of each floor; and

(c) in a building of Type A construction, the building is protected throughout by a sprinkler system (other than a FPAA101D or FPAA101H system) complying with Specification E1.5 and has—

- (i) sprinkler protection to balconies, patios and terraces, and where overhead sprinkler coverage is not achieved alongside the *external wall*, sidewall sprinkler heads are provided at the *external wall* for the extent of the balcony, patio or terrace where overhead sprinkler coverage is not achieved; and
- (ii) for a building with an *effective height* greater than 25 m—
  - (A) monitored stop valves provided at each floor level arranged to allow the isolation of the floor level containing the stop valve while maintaining protection to the remainder of the building; and
  - (B) the sprinkler system being capable of providing sufficient flow to serve the design area required by AS 2118.1 for the relevant hazard class on each floor level plus the design area required by AS 2118.1 for the floor level above, except where the former level is—
    - (aa) the floor level below the uppermost roof; or
    - (bb) any floor level that is wholly below ground; and

Figure 9 – Extract of Verification Method CV3 from the NCC Volume 1, 2019

Furthermore, Clause C3.16 calls for the construction joints and the like of a building element to have the relevant fire resistance level required, protection measures must be installed with an approved AS 1530.4 system, please refer to the below BCA extract.

C3.16 Construction joints

(a) Construction joints, spaces and the like in and between building elements *required* to be *fire-resisting* with respect to *integrity* and *insulation* must be protected in a manner identical with a prototype tested in accordance with AS 1530.4 to achieve the *required* FRL.

In the United Arab Emirates (UAE) the requirement for cavity barriers is made clear, as such is a prescriptive measure that needs to be adopted for the multi-story buildings, which have constituted cavities within external walls. Section 4.5.4 of the UAE Fire and Life Safety Code (Civil Defence Ministry of UAE, 2018) provides the following requirements, in relation to cavity barriers:

- "Cavity fire barriers shall be incorporated into façade designs, at every floor horizontally around window openings on all sides to limit fire breakout from a room into the adjacent cavity.
- Cavity fire barriers shall be incorporated into façade design at every floor vertically to restrict flame within continuous cavities of where cavities bridge the perimeter fire stopping.
- Cavity fire barrier shall be of non-combustible material.
- The installation shall ensure that compartmentation is established between the façade skin and the primary substrate and no cavity exists for fire to pass through.
- Where cavity is necessary part of a ventilated façade design and cavity needs to be maintained, an intumescent system, approved and listed for the purpose shall be fixed as a cavity fire barrier band. These intumescent bands serve as fire barriers when exposed to flames and shall expand to seal the gaps." (Civil Defence Ministry of UAE, 2018).

With reference to Figure 10, an illustration is shown showing the installation and different elements of a cavity barrier as required under the UAE Fire and Life Safety Code.

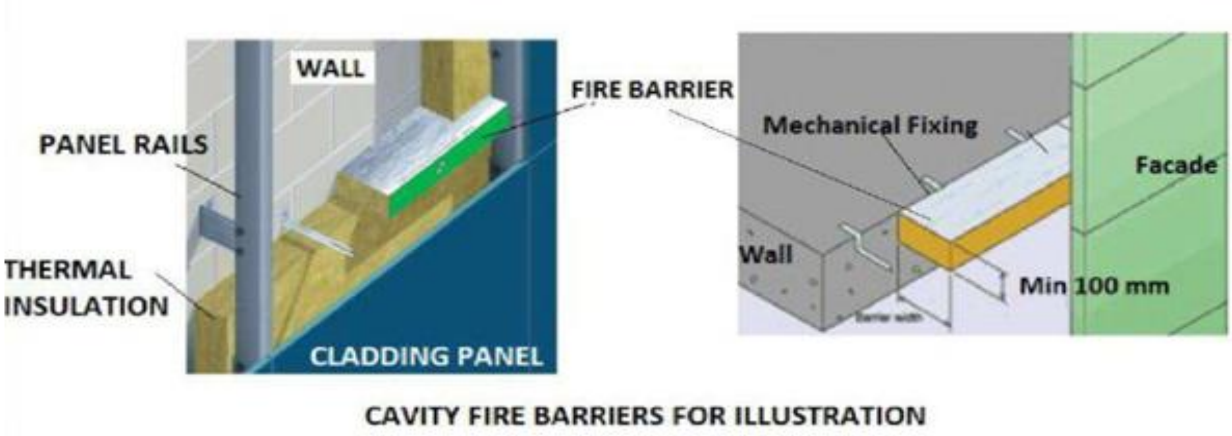


Figure 10 – Section 4.5.4 of the UAE Code describing relevant requirements for cavity barriers

2.4 Fire Behavior in Cavities and Cavity Barrier Protection

Cavities are sometime included in the design of the cladding system for insulation purposes. When the fire enters into a cavity, the fire can stretch up to 5 – 10 times the flame length to find oxygen for combustion (Chow, 2014). This phenomenon occurs regardless of the materials used for the installation of the cavity barrier, materials within the cavity and the façade attachment; as it enables the fire to spread rapidly and is unseen within the building façade system (Chen, et al., 2019) . This causes complications for firefighters as it creates hidden fires and toxic smoke build-up within the panels which may cause sudden flashover.

As most cavities are air ventilated cavities, a façade fire generally enters into it as it is one of the quickest spreading pathways. The ventilated façade is a multilayer system consisting of the following elements:

- Substructure; including the buildings slab edge, external wall or columns, which the façade is attached to;
- Insulation; located on the exterior side of the supporting wall;

- Air chamber; the cavity formed by the separation between the cladding and insulation (fixed to the building wall);
- Cladding; is the outer face of the façade, which can comprise of many different non-combustible and combustible materials. (Giraldo, et al., 2013)

There are three (3) common ways a fire can spread vertically through the cavity of a building, they are as follows: (Carlsson, 1999)

1. Through the window openings;
2. Through the surface of the cladding (i.e. external fire burns the façade attachment and enters into the cavities)
3. Through the ventilating cavity, this can occur from an internal fire if there is no spandrel separation.

This research will cover all three (3) aspects of fire spread described above, however the main focus will be for fires within the cavity, as we are trying to determine the effectiveness of cavity barriers. To further understand how a fire can be transmitted from one place to another, the three main mechanisms of fire spread shall be understood.

- Conduction related to the transfer of heat associated with solids and the thermal conductivity of the materials;
- Convection relates to the movement of hot air; and
- Radiation related to openings acting as radiating bodies and emitting thermal radiation at elevated temperatures.

In terms of external cladding building fires, any one of the above three mechanisms can apply.

The hazards associated with the fire spreading through the cavity are as follows:

- **Fuel**: the use of combustible building elements within cavities, such insulation and sarking will increase the intensity of the fire.
- **Cavity size and chimney effect**: fire spread in ventilated facades occurs through the windows and cavities. This may occur at the same time, as the flames confined

by the cavity become elongated due to the air drafting vertically leading to a fire 5 – 10 times the size of a normal fire in open space. (Chow, 2014)

Data and results taken from previous studies conducted on the above two (2) factors have been taken into consideration in this research paper, as such the findings are concluded in the following subsections.

2.4.1 Non-combustible Cavity Fire – Research Paper 1 Review

It was shown in the research paper by Kolaitis in (2014) (Kolaitis, et al., 2014), that a fire within a cavity that has no fire barriers and comprises non-combustible elements, maintained a temperature of less than 180 degrees C. Even though gaseous combustion products may manage to penetrate into the air cavity of the VF system, no consistent flaming conditions are established

The aim of the study done by Kolaitis (2014) was to investigate the fire behavior of a typical Ventilated Façade (VF) system fire, in which a full-scale compartment-façade fire test was carried out. The test measured the temporal variation of several important physical parameters, such as gas, and wall surface temperatures, gas velocities and fuel mass loss rate. No combustible elements and cavity barriers within the cavity or VF were used, aiming to investigate the main aerodynamic and thermal phenomena affecting the flow of hot gases and flames in the air cavity.

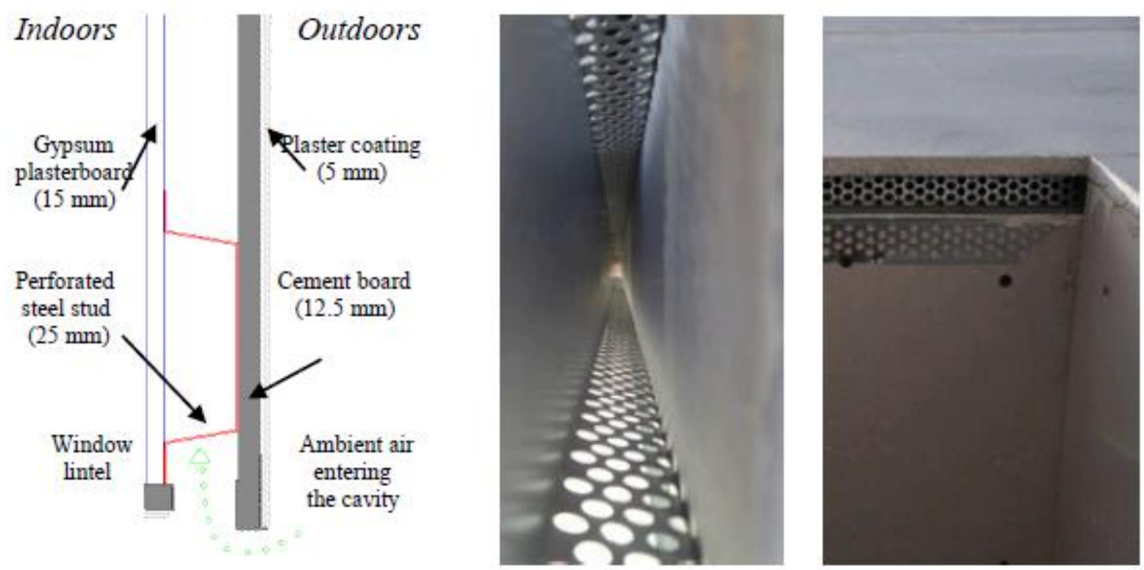


Figure 11 – Extract taken from the research paper conducted by Kolaitis 2014, showing Ventilated Façade System build up

2.4.2 Impact of Cavity Width – Research Paper 2 Review

An experimental study was documented by Karlis Livkiss dated (2018) (Livkiss, 2018) to show the correlation between flame height and cavity widths. In this particular study to keep things constant non-combustible construction was used. It was observed that as the cavity width was reduced the plume flow appeared to be more vertically oriented and the flames filled the entire cavity width. As such it was clearly indicated that the flame heights increased with reduced cavity width, as shown below in Figure 12.

The experimental setup consisted of two parallel facing non-combustible plates (0.8 9 1.8 m) and a propane gas burner placed at one of the inner surfaces. The cavity width between the plates ranged from 0.02 m to 0.1 m and the burner heat release rate was varied from 16.5 kW to 40.4 kW per m of the burner length.

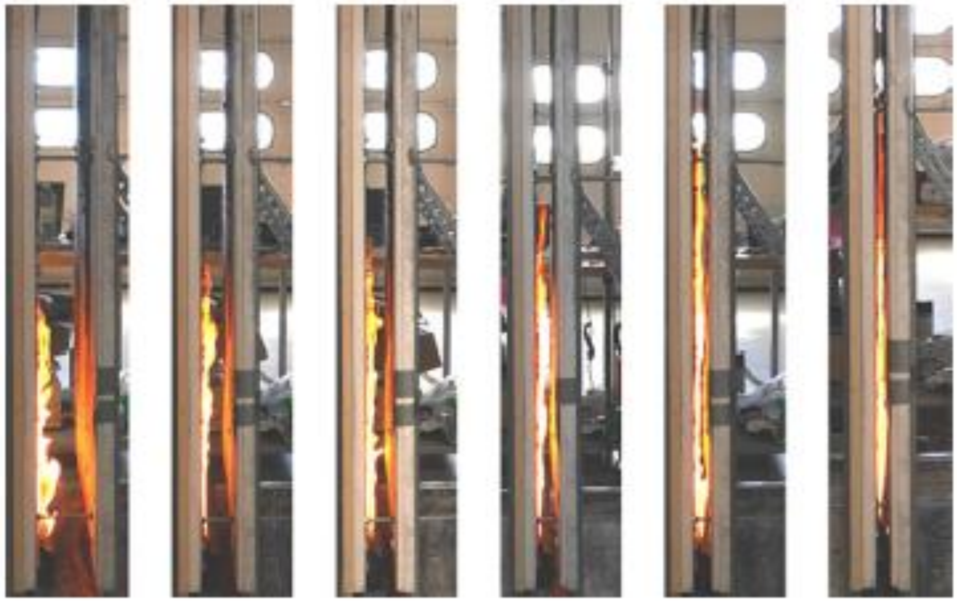


Figure 12 – Photos of the test conducted by Karlis Livkiss showing flame height within different cavity widths

2.5 Fire Dynamic Simulator (FDS)

As part of this research, a computational simulation will be carried out to try and determine the effectiveness of cavity barriers in used in Ventilated Façade Systems, with combustible facades. The software described, Fire Dynamics Simulator (FDS), is a computational fluid dynamics (CFD) model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires. (National Institue of Standards and Technology, 2019).

FDS is used for modeling design of smoke handling systems and sprinkler/detector activation studies, as well as modeling residential and industrial fire scenarios. FDS has been aimed at solving practical fire problems in fire protection engineering while proving a tool to study fundamental fire dynamics and combustion. (National Institue of Standards and Technology, 2019).

2.5.1 Numerical Tools

The numerical simulations are performed with the CFD code FDS version 6.7.4. FDS is a computational code in fluid dynamics that incorporates a combustion model and a large-scale model (LES) for the description of turbulent flows. This tool allows 3D modelling of the computational domain. It considers heat transfer at walls, ventilation conditions for the removal of hot gases and air intake.

The Navier- Stokes equations are solved in the limit of low Mach number, thermally driven flow with an emphasis on smoke and heat transport from fires. The radiative heat transfer is included in the model through the solution of the radiative transport equation for a grey gas (National Institue of Standards and Technology, 2019).

The fuel burnout in each solid numerical cell is accounted for by the specification of the combustible mass and heat of combustion of the object through the bulk density parameter. Thus, when the mass contained in each solid cell is consumed, the solid disappears from the calculation cell by cell. This feature is used to account for the destruction of the cladding, as observed experimentally with ACM-PE experiments. The heat transfer at walls is simulated with a subsequent heat of vaporization to account for the energy loss due to the vaporization of the solid fuel.

The accuracy of the fire model predictions depends on the number and size of cells (the mesh) assigned to the physical space being modelled. In each cell, gas velocity and mass, gas temperature and gas concentration are evenly distributed and vary with time.

The mesh describes how many cubic cells are used within the volume and therefore the resolution of the model. The computational time is directly proportional to the mesh size.

In order der to get an approximate value of the mesh size, the non-dimensional equations (D*/dx), Where D* is shown in Equation 1 below.

$$\boldsymbol{D}^{*} = (\frac{\dot{Q}}{\rho\infty cpT\infty\sqrt{g}})^{\frac{2}{5}}$$ **Equation 1**

2.5.2 The Use of Cavity Barriers in VF Systems – Research Paper 3 Review

A similar study documented by María P. Giraldo, Ana Lacasta, Jaume Avellaneda and Camila Burgos in 2013 (Giraldo, et al., 2013) shows that the use FDS is capable of modelling a cavity fire, the aim of the study which is titled "Computer-simulation study on fire behaviour in the ventilated cavity of ventilated façade systems" is to determine some aspects of fire propagation through the ventilated cavity in ventilated façade systems and how to avoid fire spread outside the building.

In the study referenced a scenario representing a fire in a living room is considered. The fire starts on a couch in the ground floor of the scenario. To achieve this, an ignition source of 400 cm^2 is placed on the surface of the couch. This source is characterized by a burner with a heat release rate of 1000kW/m^2. Once the fire reaches the stage of flashover, it spreads to the outside through the windows, at which point fire enters to the cavity. Fire growth occurs according to the calculation performed by the software. The FDS solves the equations governing the simulated system and provides graphical and numerical data for each scenario. (Giraldo, et al., 2013).

With reference to Figure 13, an extract from the modelling conducted in the study is shown, displaying the effects of the fire that was simulated within the room, spreading into the cavity and eventually onto the building façade, both fire and smoke spread are displayed.

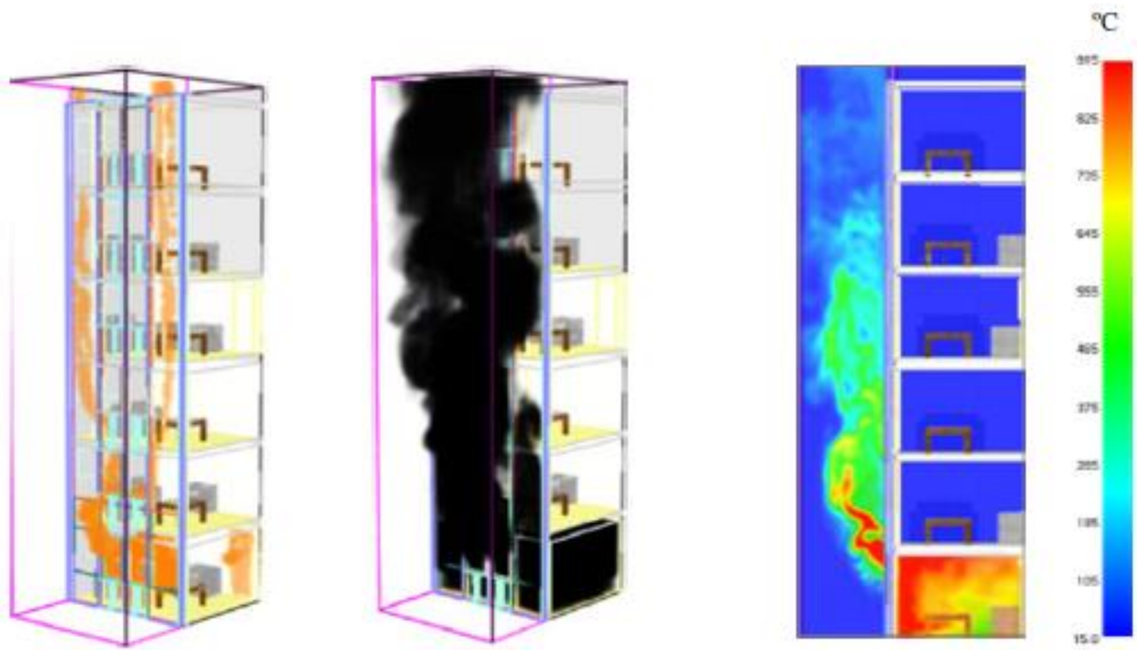


Figure 13 – Extract from the modeling conducted by (Giraldo, et al., 2013), showing the spread of fire and smoke through the cavity and building façade from a room fire

The study deduces that the use of cavity barriers greatly reduces the spread of fire through the ventilated cavity and on to the upper floors. However, it is to be noted that since the study was conducted using computational analysis, it is not possible to obtain data on the fire resistance of elements or on the degradation of materials exposed to flames, but rather their influence on fire dynamics.

2.5.3 Sweden SP Fire 105 Façade Test

The base model simulated in this paper comprises of the SP Fire 105 test, this is used to validate the simulation results as a comparison, after which the variables will be applied to determine the effects of cavity barriers on different types of façades.

The experimental setup described in the SP Fire 105 (Van Hees, 2000) is intended for determining the fire behaviour of external wall assemblies and façade claddings exposed to a fire from an apartment. The test setup was used in this research paper simulated the setup designed for the SP Fire 105, with the incorporation of horizontal cavity barriers on the slab edge of each level.

With reference to Figure 14, the SP Fire 105 evaluates a large-scale façade fire on a three (3) story building where the first level is the fire room containing the Heptane fire source with a story height of 1.3 m and Level 1 and Level 2 being 2.7 m each, the slabs between each level was assumed to be a thickness of 0.2 m making the total height of the rig 6.7 m. The fire exposure lasts around 15-20 minutes with the fire source feature comprising 60 L of Heptane burning in trays. (Anderson & R, 2013)

The performance criteria of the façade system are maximum temperatures of the combustion of gases and maximum heat flux to the specimen in the middle of the first fictitious window as indicated below in Table 2.

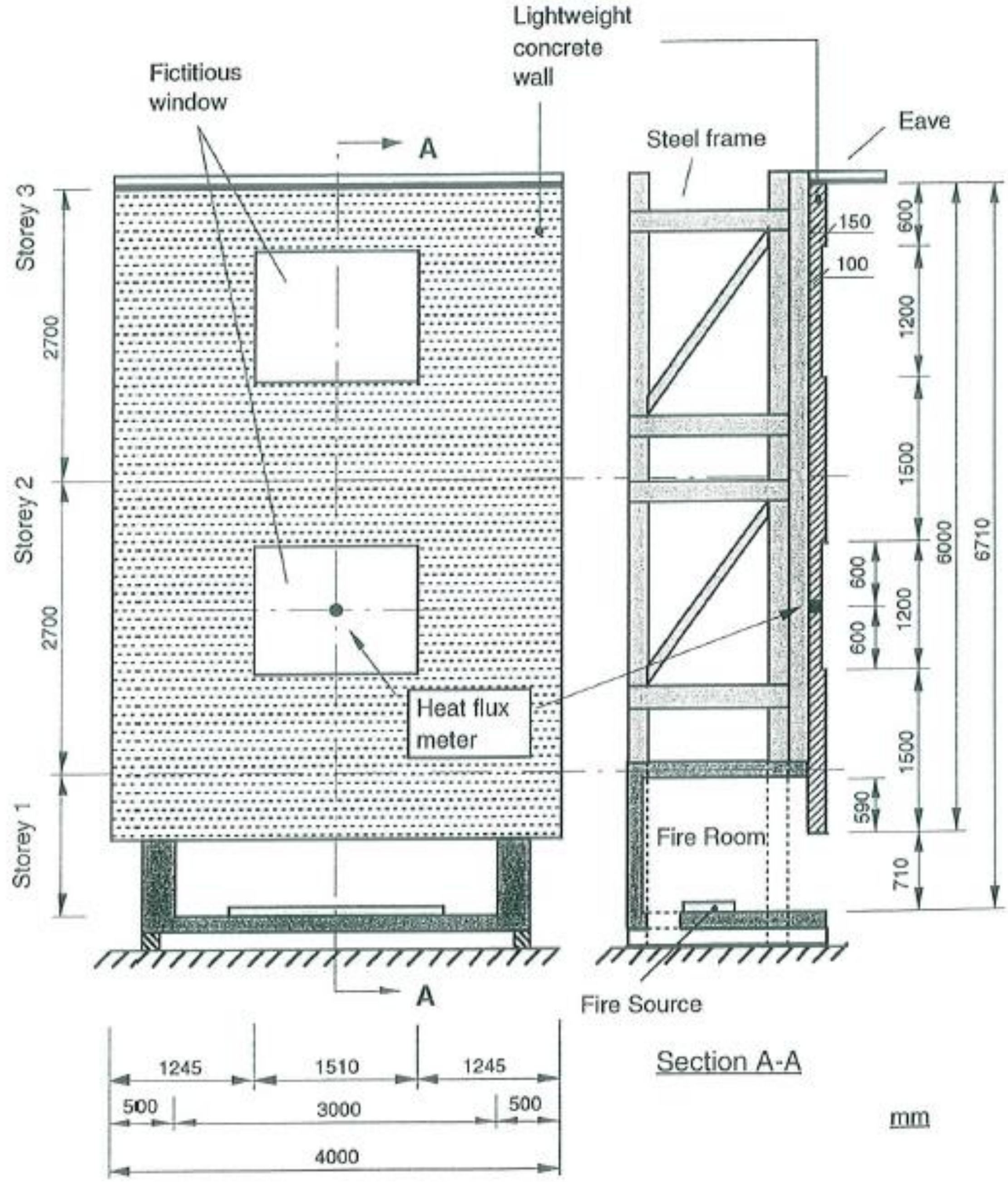


Figure 14 – SP Fire 105 Test rig (Swedish National Testing and Research Institute, 1985)

The key parameters and performance criteria for the SP Fire 105 test are provided below in Table 2.

Table 2 – Key parameters of the SP Fire 105 large scale façade test

SP Fire 105 Large Scale Façade Test – Key Parameters	
Country used	Sweden
Fire Source	Heptane fuel tray Filled with 60 L heptane. Approx. 2.0 MW peak HRR
Fire Exposure	15 kW/m2 at 4.8 m above opening for at least 7 min; 35 kW/m2 at 4.8 m above opening for at least 1.5 min; <75 kW/m2 at 4.8 m above opening at all times
Duration	15 Minutes
Geometry	Total height: 6.7 m Fire compartment: 3.0 m wide x 1.6 m deep x 1.3 m high
Test Measurements	Heat Flux Device provided 2.1 m above opening (centre of fictitious first storey window)
Performance Criteria	
External Fire Spread	No fire spread >4.2 m above opening (bottom of fictitious window) Temps at the eave must not exceed 500^{o}C for more than 2 min or 450^{o}C for more than 10 min For buildings > 8 stories high or hospitals, heat flux <80 kW/m^2, 2.1 m above opening
Internal Fire Spread	No fire spread > 4.2 m above opening (bottom of second storey fictitious window)
Burning Debris	To be reported but criteria not specified by standard
Mechanical Behavior	No large pieces are permitted to fall from the building

The above described test has been modelled using FDS 6.7.4 to simulate an apartment fire starting on lower levels spreading to the external façade and vertically up the building. The modelling conducted is described in the Methodology section of this paper.

2.6 Burning Behaviour of Different Cladding Types

To understand the impact cladding has on fire spread, the burning behaviour of different types of aluminium composite cladding panels was investigated. In this paper the research conducted by BRE Global is investigated. It is to be noted that BRE Global were commissioned by the Technical Policy Division of the Ministry of Housing, Communities and Local Government (MHCLG) commissioning and the research project was titled "The fire performance of cladding materials". (BRE Global, 2020).

The aim of the project was to investigate the burning behaviour of selected types of non-ACM (non-aluminium composite material) cladding products using physical testing at intermediate scale in a laboratory setting to identify products of potential concern. These results are compared to the burning behaviour of ACM products with a combustible core, such as the cladding used on the Grenfell Tower.

The test included twenty-two (22) different types of products comprising of but not limited to the following:

- Aluminium Honeycomb panels;
- High pressure laminate panels;
- Zinc composite panels;
- Copper composite panels;
- Reconstituted stone and brick slip systems; and
- Untreated timber products.

In each case, the results from the experiments were compared with the base contribution from the ignition source and the measured contribution from the Polyethylene Aluminium Composite Material (PE ACM) investigated as part of the calibration process used to develop the methodology. In each case, the performance analysis was based on the overall contribution to fire growth and the potential for development of a cavity fire. (BRE Global, 2020)

The focus in this paper will be the comparison of the results taken from the following types of cladding:

- ACM PE (99% combustible core)
- ACM FR (20% - 30% combustible core)
- ACM A2 (non-combustible)

2.6.1 ACM PE Testing

With reference to Figure 15 and Table 3, the results of the fire test conducted on the PE ACM is shown at intervals of 5 minutes to a total time of 25 minutes, after which the test was stopped due to the burning of the cladding.

It was observed that the fire developed very quickly and after only 5 minutes, the fire breached the cavity. Furthermore, a molten plastic pool fire started at the bottom of the rig. After 7 minutes the flame height above the rig was 2 m, with sustained flaming inside and outside the cavity observed. After 10 minutes, the fire started to spread laterally, which caused the ACM PE to burn away. At this point falling debris and droplets of fire were observed. A peak HRR of 1425 kW was reached at 8.7 minutes, with a cavity temperature of 1003^{o}C and external temp of 944^{o}C, the temperature at a height of 3 m was measured at 656^{o}C and area burned approximately 5.1 m^2 as shown in Table 3.

5 minutes from ignition

10 minutes from ignition

20 minutes from ignition

25 minutes from ignition

Figure 15 – Intermediate fire test on PE ACM showing results after 25 minutes

Table 3 – Summary of measured parameters and visual observations during fire test

Max external temp (^{o}C)	**Max cavity temp (^{o}C)**	**Max temp (^{o}C) at 3 m**	**Time to peak HRR (min)**	**Peak HRR (kW)**	**Max heat flux at 3 m**
944	1003	656	8.7	1425	>100
Burning droplets	**Burin through**	**Time to burn (min)**	**Area consumed (m^2)**	**Vertical fire spread**	**Horizontal fire spread**
Significant	Yes	2	~5.1	Yes	Yes

2.6.2 ACM FR Testing

With reference to Figure 16 and Table 4, the results of the fire test conducted on the FR ACM is shown at intervals of 5 minutes to a total time of 25 minutes, after which the test was stopped.

It was observed that there were no significant burning debris or droplets during the duration of the fire test. A discoloration of the panels was observed in the area of direct flame exposure. After about 21 minutes, the fire consumed the aluminium panel and preached inside the cavity. No significant changes to the burning behaviour were recorded as well as no significant vertical and lateral fire spread on the surface of the FR ACM was observed. A peak HRR of 338 kW was reached at 10.1 minutes, with a cavity temperature of 1017^{o}C and external temp of 975^{o}C, the temperature at a height of 3 m was measured at 198^{o}C as shown in Table 3.

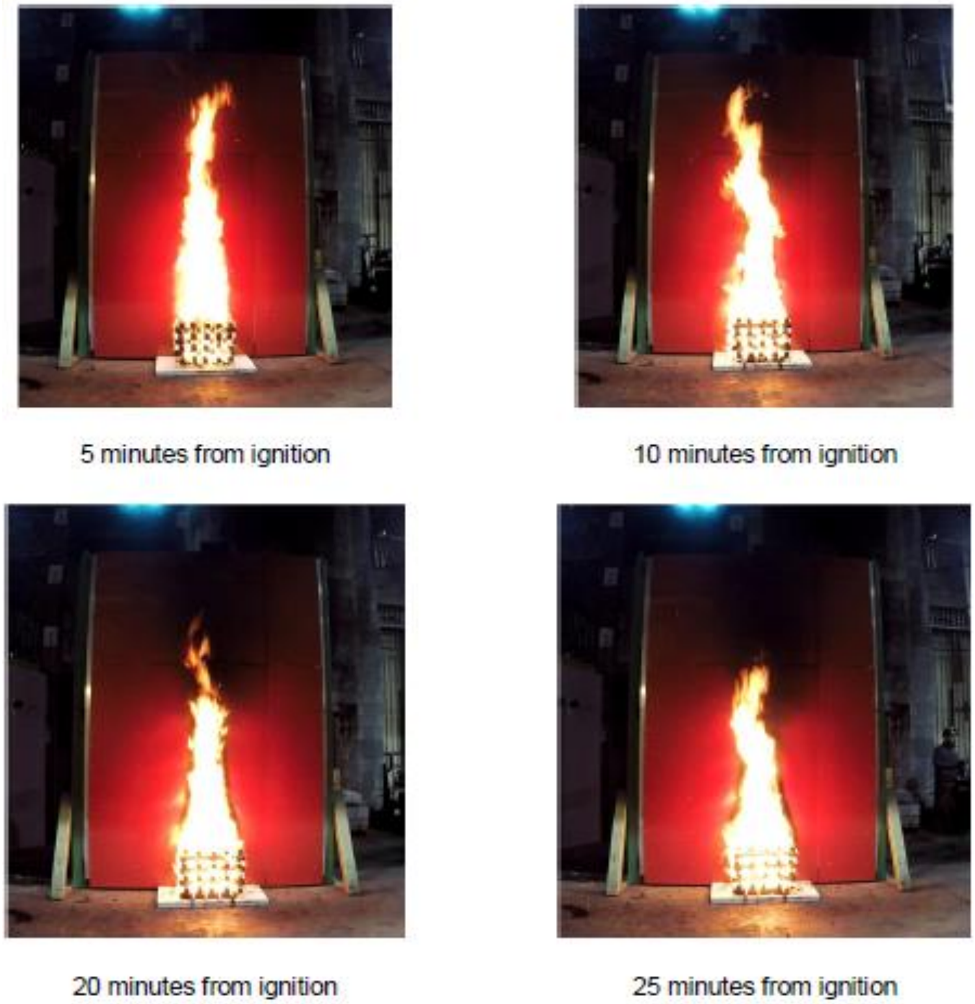


Figure 16 – Intermediate fire test on FR ACM showing results after 25 minutes

Table 4 – FR ACM Summary of measured parameters and visual observations of fire test

Max external temp (°C)	**Max cavity temp (°C)**	**Max temp (°C) at 3 m**	**Time to peak HRR (min)**	**Peak HRR (kW)**	**Max heat flux at 3 m**
975	1017	198	10.1	338	20.5
Burning droplets	**Burin through**	**Time to burn (min)**	**Area consumed (m^2)**	**Vertical fire spread**	**Horizontal fire spread**
Not Significant	Yes	22	~0.5	No	No

2.6.3 ACM A2 Testing

With reference to Figure 17 and Table 5, the results of the fire test conducted on the FR ACM is shown at intervals of 5 minutes to a total time of 25 minutes, after which the test was stopped.

It was observed that there were no significant burning debris or droplets during the duration of the fire test. A discoloration of the panels was observed in the area of direct flame exposure. The aluminium face started to delaminate from the core in the direct flame impingement location. Local buckling and distortion were observed on the panels. No significant changes to the burning behaviour were recorded as well as no significant vertical and lateral fire spread on the surface of the A2 ACM was observed. A peak HRR of 338 kW was reached at 10.1 minutes, with a cavity temperature of 1017^{o}C and external temp of 975^{o}C, the temperature at a height of 3 m was measured at 198^{o}C as shown in Table 3.

The A2 ACM panels were burnt away only at the areas were the flame was in direct contact with the panel as shown below in Figure 18.

5 minutes from ignition

10 minutes from ignition

20 minutes from ignition

25 minutes from ignition

Figure 17 – Intermediate fire test on A2 ACM showing results after 25 minutes

Table 5 – A2 ACM summary of measured parameters and visual observations of fire test

Max external temp (°C)	**Max cavity temp (°C)**	**Max temp (°C) at 3 m**	**Time to peak HRR (min)**	**Peak HRR (kW)**	**Max heat flux at 3 m**
706	140	176	19.4	333	8
Burning droplets	**Burin through**	**Time to burn (min)**	**Area consumed (m^2)**	**Vertical fire spread**	**Horizontal fire spread**
Not Significant	Yes	22	~0.5	No	No

Figure 18 – After effects of cladding after 25 minutes of 300 kW fire

2.7 Summary of Literature Review

The literature review provided, gives a summary of three (3) independent research papers conducted about Ventilated Façade (VF) systems, cavity fires and the behaviour of different cladding products such as PE ACM, FR ACM and A2 ACM was also investigated through the research conducted by (BRE Global, 2020). In the aim of providing further insight on the main objectives of this research, which include:

- To establish the behaviour of fire on the external façade and within the cavity of the external walls;
- To identify how effective the installation of cavity barriers is to mitigate vertical fire spread through building façades and cavities; and
- To determine if cavities barriers will aid in the retention of combustible building elements, where otherwise not permitted under DtS provision.

The first paper reviewed which was documented by Kolaitis in (2014), looked at the behaviour of a fire within a cavity that is comprised of non-combustible elements with no thermal insulation and sarking present, the aim of this research was to find out if the air flow or chimney effect created by the presence of a cavity would impact on the spread of fire. In this test a full-scale compartment fire was conducted, and the results showed that a fire within a cavity that has no fire barriers and comprises non-combustible elements, maintained a temperature of less than 180 degrees C.

The second paper reviewed which was documented by Karlis Livkiss dated (2018), looked at the effect the width of a cavity has on the fire or spread of fire within. It was concluded that the width does in fact play a role on the flame height based on the full scale testing conducted and that the narrower the cavity the higher the flame, this was more evident as the intensity of the flame grew.

The third paper reviewed which was documented by María P. Giraldo, Ana Lacasta, Jaume Avellaneda and Camila Burgos in (2013), looked at the effects a room fire has on the spread of smoke and fire through a cavity, using Fire Dynamics Simulator (FDS) a form of computational modelling, similar to what will be conducted in the second portion of this research paper. The results shown in the referenced paper lead to the conclusion that the use of cavity or fire barriers will help mitigate fire and smoke spread via a cavity fire, as such is in line with the hypothesis proposed in this research paper.

The fourth research investigated was the BRE Group experimental intermediate testing conducted on different types of cladding products (BRE Global, 2020). This research was undertaken to determine the burning behaviour of them and make a comparison between a Polyethylene (PE) core, with a Fire Retardant (FR) core and a non-combustible core.

The results showed that the PE ACM sustained significant burning and produced a good amount of burning debris and burning droplets with the temperatures within the cavity and at a height of 3 m being very high. The FR ACM products did not contribute much to the fire spread as it was observed that the cladding only burnt away at the point of direct flame impingement and the flame height did not increase a significant amount, it is to be noted that the fire burnt through the cladding, as such the fire spread into the cavity. The non-combustible cladding showed the best results as the fire did not burn through the panel completely and the fire did not enter the cavity, however the aluminium showed signs of melting and caused some sort of molten to spill down the rig. However, the non-combustible cladding did not contribute to flame propagation and only melted at the point of direct flame impingement.

It is to be noted that the amount of variables involved in testing a Ventilated Façade fire make it difficult to predict how a fire will behave in every building and as such cannot be generalised, the parameter inputs given in the FDS modelling or a full scale fire test shall be specific and conclusions drawn will only be applicable in the scenarios analysed. Parameter inputs include but are not limited to the following; cavity width, materials used within cavities, and type of cavity barrier used, if any at all.

3 CHAPTER III: METHODOLOGY

The approach to this study will consist of a combination of Fire Dynamics Simulator (FDS) (National Institue of Standards and Technology, 2019) computational modelling and a comprehensive literature review of existing tests conducted.

3.1 Overall Project Procedure

This research paper consists of the following methodology:

1. Literature review to establish

    a. DtS provisions on cavity barriers: this will be undertaken to establish the existing requirements for cavity barriers and provide a better understanding as to why they have not yet been mandated in the NCC, for multistorey buildings (with the exception of fire protected timber construction).

    b. Any previous studies on the same or similar topic: data will be collected nationally and internationally about the use of cavity barriers and perimeter fire stopping, including test reports, FDS simulation and physical model tests.

    c. Vertical fire spread criteria: This part may include input and research on critical temperature or heat flux for breaking of upper level windows and/or ignition of combustibles, if any. These criteria will be used in the analysis of FDS simulation results to determine whether a barrier is effective or not.

2. The model will be validated against the performance criterion Setout in the SP Fire 105 test described above in Section 2.5.3 and shown below in Table 6 and the large scale test results taken from the Babrauskas tests of the SP Fire 105 test (Babrauskas, 1996). The base model with non-combustible cladding without the use of cavity barriers will be simulated and compared to the criterion set out in the SP Fire 105 test. After which the four other different models will be simulated, and the results compared alike.

Table 6 – Performance criteria of the SP Fire 105 test used as validation technique

Performance Criteria	
External Fire Spread	No fire spread >4.2 m above opening (bottom of fictitious window) Temps at the eave must not exceed 500°C for more than 2 min or 450°C for more than 10 min for buildings > 8 stories high or hospitals, heat flux <80 kW/m^2, 2.1 m above opening
Internal Fire Spread	No fire spread > 4.2 m above opening (bottom of second storey fictitious window)
Burning Debris	To be reported but criteria not specified by standard
Mechanical Behavior	No large pieces are permitted to fall from the building

3. Conceptual design of cavity barrier for a typical/example building case: Once the model is validated against the experimental results, it will be modified to simulate the more complicated conceptual design case. A breakdown of how cavity barriers are expected to react to fire in terms of fire resistance levels and how they are installed in the building frame.

4. Performance evaluation of the design through FDS simulation: review of the results and as well as the FDS simulation generated to draw a sound conclusion on the use

of cavity barriers and perimeter fire stopping. This process will generally comprise the following:

a. The use of Pyrosim Fire Dynamics Simulator (FDS) to simulate a fire within a cavity to see the effects of cavity barriers as compared to no cavity barrier protection;

b. The modelling proposed in this research paper includes a simulation of the SP Fire 105 test (Swedish National Testing and Research Institute, 1985), this is a large-scale fire test conducted in Sweden. Please refer to Section 2.5.3 for more information on this test.

c. The SP Fire 105 test method for façade system was defined in 1985 and simulates a three-story apartment building, height 6.7 m, width 4 m and depth 1.6 m shown below in Figure 19. The experimental setup is intended for determining the fire behaviour of external wall assemblies and façade claddings, exposed to heat and flames coming out from an opening in a room with a fully developed apartment fire. The test is designed to evaluate external fire spread on the surface, internal fire spread in enclosed burnable components in the system, as well as recording falling down of parts including the occurrence of burning droplets. (Anderson & R, 2013).

d. The fire exposure lasts around 15 – 20 minutes, the fire source is a tray (width × length × height: 500mm × 2000mm × 100 mm) filled with 60 litres of heptane. In the standard fire test two thermocouples are placed under an eave, six meters above the fire room and a heat flux meter is placed in a lower fictitious window 2.1 meter above the fire room, as per Figure 19.

e. The SP Fire 105 Test will be simulated using FDS to evaluate the results against another test conducted for comparison, the test will be simulated with and without cavity barriers to determine the effectiveness of the use of cavity barriers in external and cavity fire spread. The results of the modelling conducted in this paper will be evaluated against the results of the actual fire test provided in the paper by (Anderson & R, 2013). Furthermore, the results will be assessed against the acceptance criteria set out for the SP Fire 105 Test as indicated in Table 1 of (Shulz, et al., 2020).

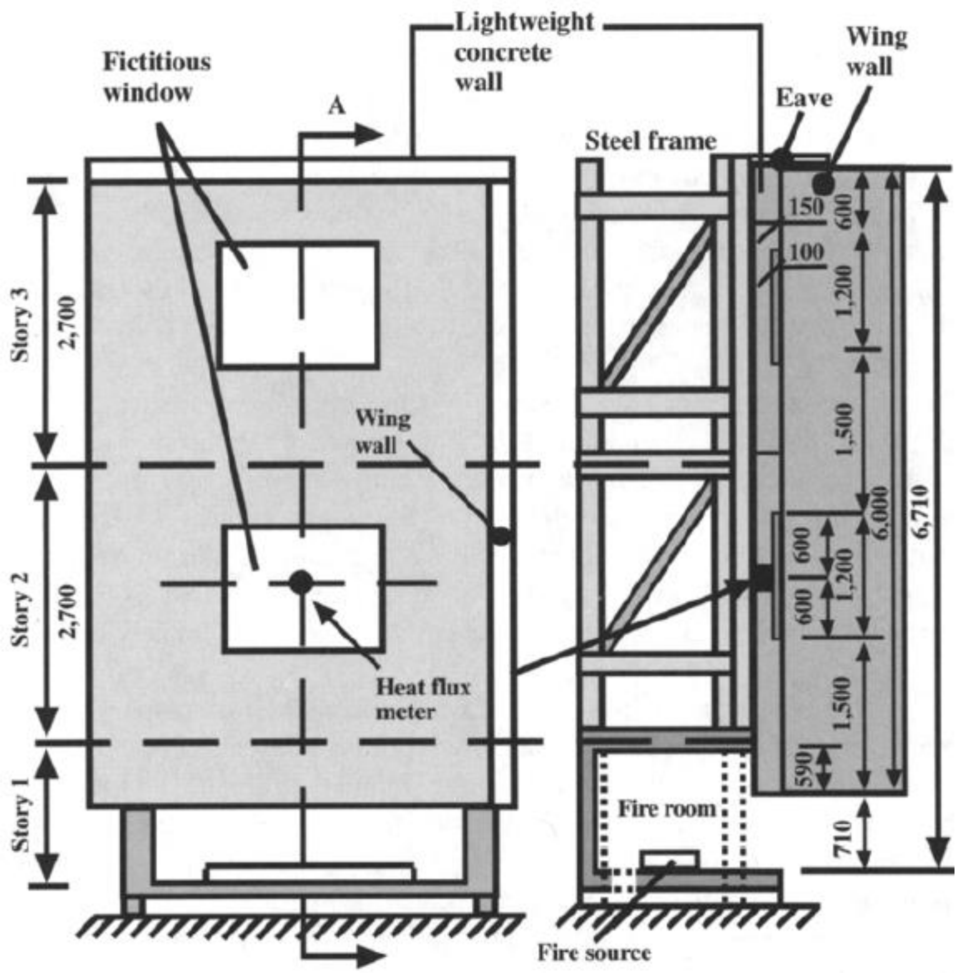


Figure 19 – SP Fire 105 Test Rig Details

5. Further analysis and drawing conclusion: based on the literature review, design of cavity barriers, and FDS modelling, a conclusion will be determined, as to whether or not the effectiveness of cavity barriers and perimeter fire stopping, can potentially justify the retention of combustible elements on building façades (i.e. Cladding).
6. A look at test data conducted around the world to make a comparative assessment between buildings with and without cavity barriers will be documented in the research.

3.2 Modelling Scenarios

The method used within this research paper to study the effectiveness of cavity barrier against vertical fire spread is through FDS modelling. As such, this section describes the different scenarios modelled.

There was five (5) different design scenarios input into the FDS modelling to provide the most accurate results, comprising the following:

1) **Base Model** – This model was simulated to act as a validation technique for the results of the variable models. In this model the SP Fire 105 model was replicated and simulated for 900 s, the respective heat fluxes and temperatures from the devices input will be compared with the results of the test results shown in the research paper documented by Johan Anderson and Robert Jansson McNamee (Anderson & McNamee, 2012). In this model the SP Fire 105 test was replicated and did not comprise any façade attachments to the external light weight concrete wall with thickness of 150 mm, the wall constitutes a window on Level 1 and Level

2 that is indented 50 mm into the 150 mm wall with dimension of 1500 mm wide by 1200 mm high. The model as described above comprises 3 storeys with the first level being the fire room with a height of 1300 mm and 2700 mm subsequent levels. A 450 mm eave protrusion was provided on the top of the rig, this is expected to stop the flame from extending past it if it is reached to that height.

2) **Model 1** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITH** the installation of a cavity barrier at the slab edge, the façade attachment comprises aluminium composite panel with Polyethylene (PE) combustible cladding as shown in Figure 21;
3) **Model 2** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITHOUT** the installation of a cavity barrier at the slab edge, the façade attachment comprises aluminium composite panel Polyethylene (PE) combustible cladding, as shown in Figure 22;
4) **Model 3** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITH** the installation of a cavity barrier at the slab edge, the façade attachment comprises non-combustible construction, as shown in Figure 23; and
5) **Model 4** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITHOUT** the installation of a cavity barrier at the slab edge, the façade attachment comprises non-combustible construction, as shown in Figure 24.

Note: The windows have been opened in these four models and closed in the base model as per SP Fire 105

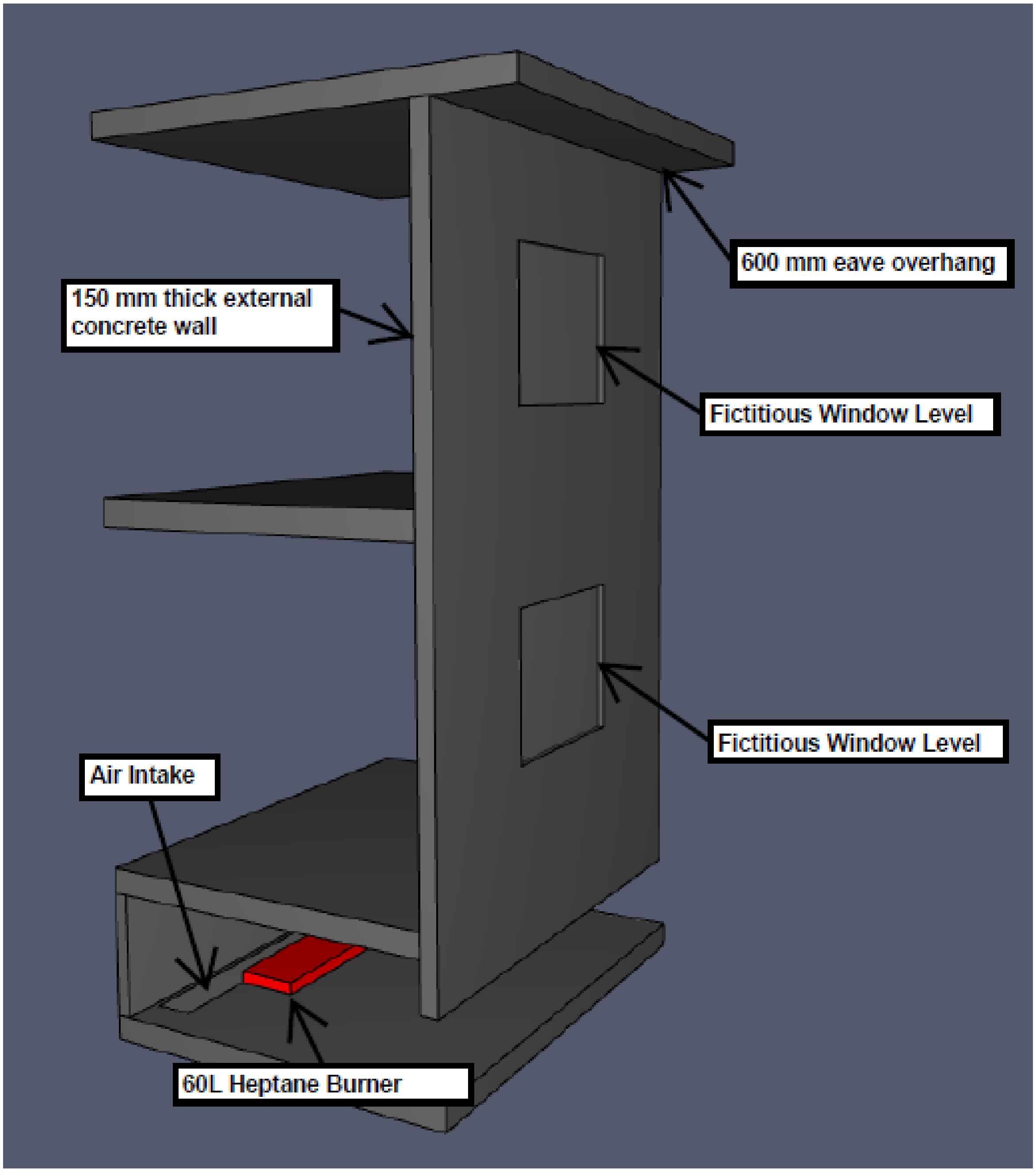


Figure 20 – Base model replicating SP Fire 105 test

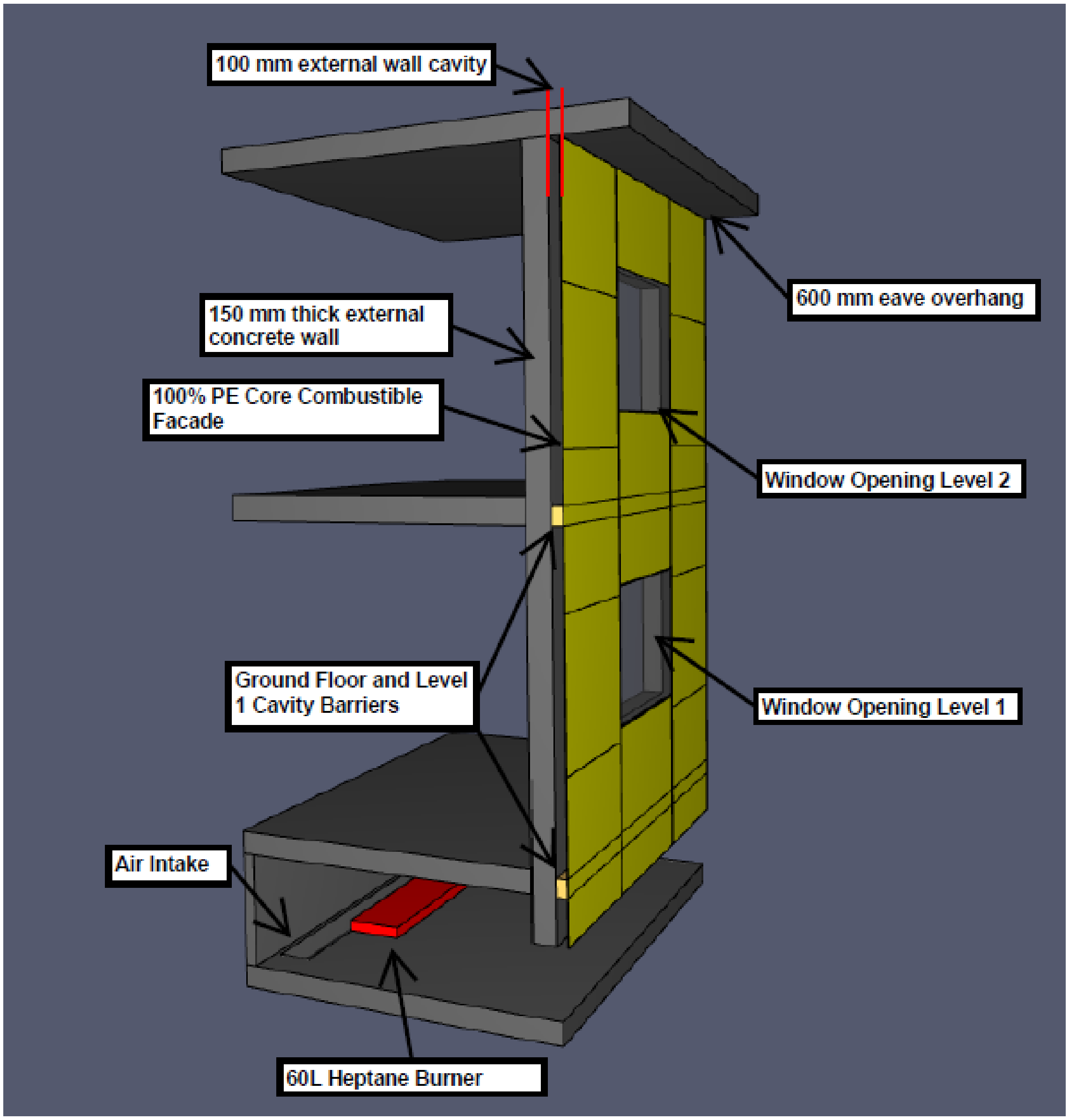


Figure 21 – Snapshot of Model 1 from the FDS modelling done

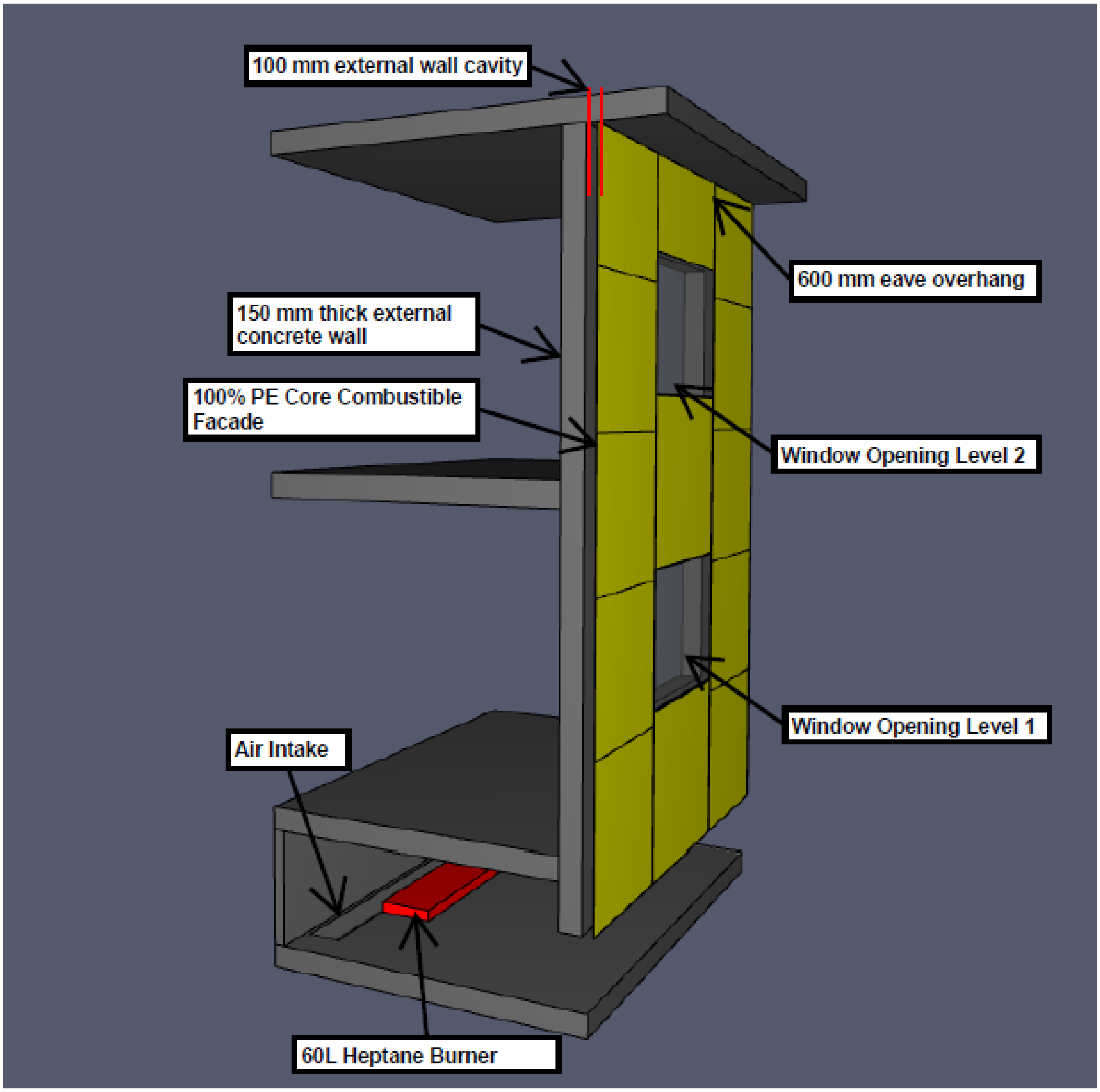


Figure 22 – Snapshot of Model 2 from the FDS modelling done

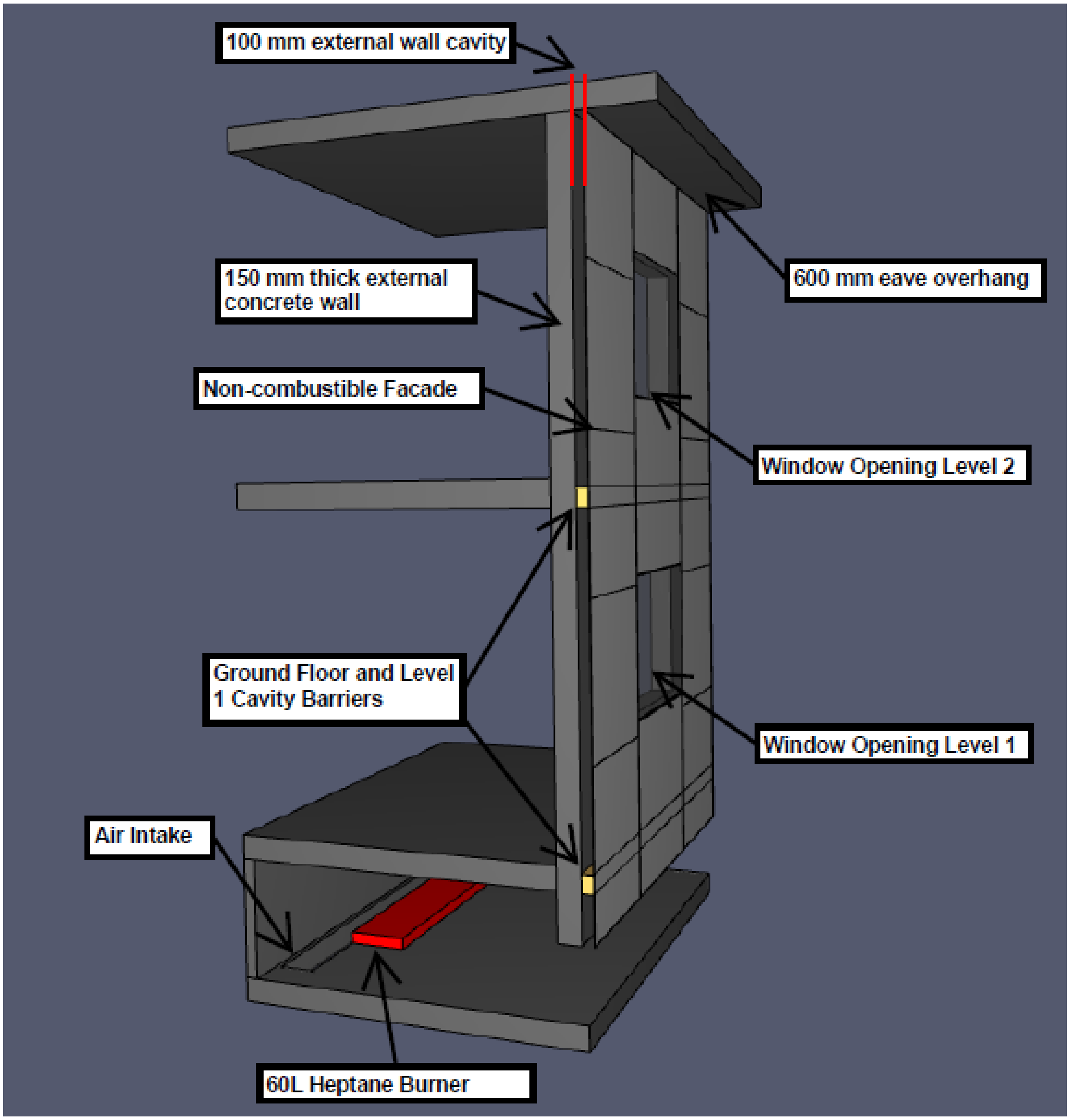


Figure 23 – Snapshot of Model 3 from the FDS modelling done

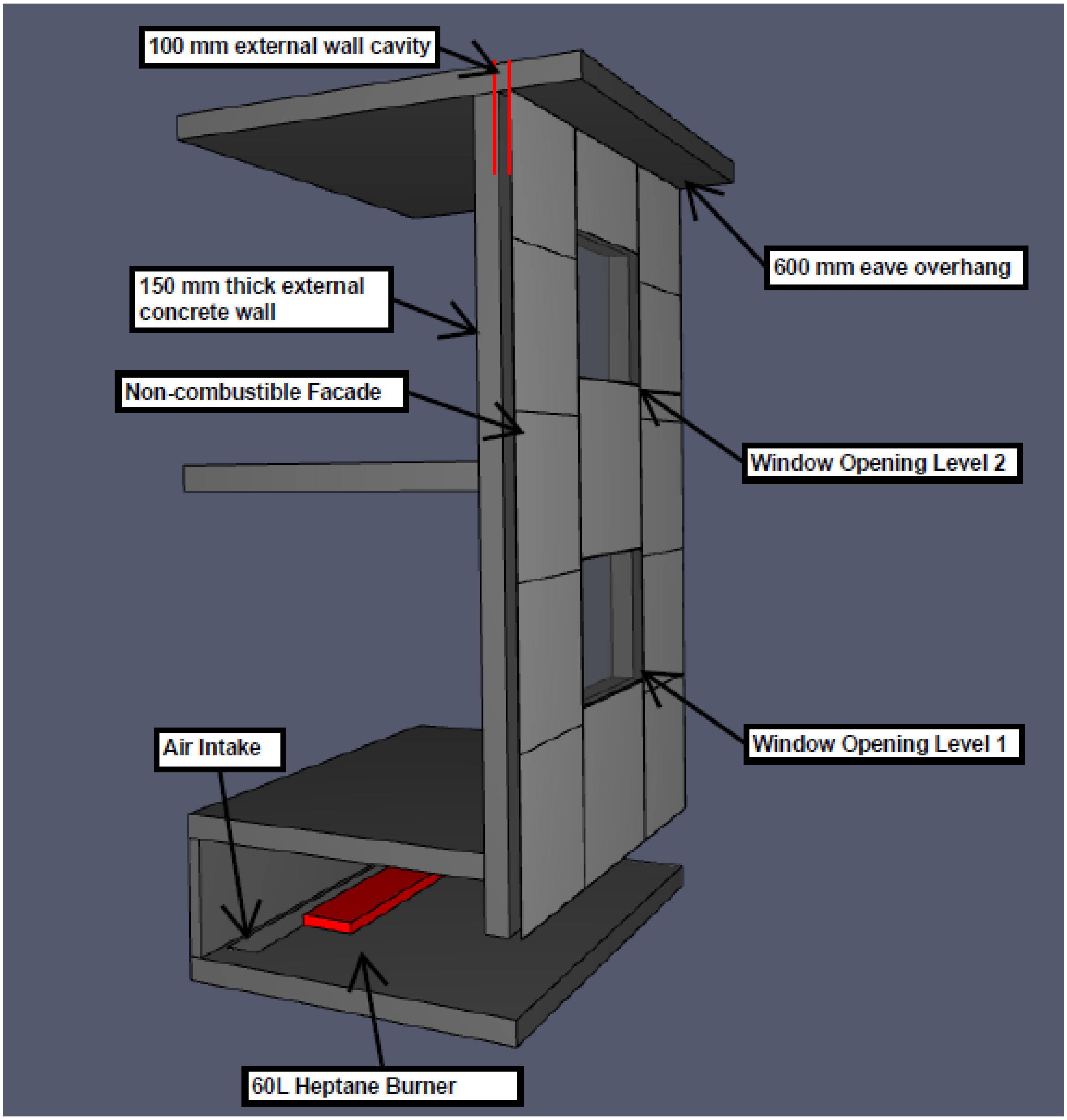


Figure 24 – Snapshot of Model 4 from the FDS modelling done

3.3 Modelling Design Parameters:

To keep the model as accurate as possible, there will be a set of constant inputs and a set of variable inputs; the variables are briefly described above in the description provided for each different scenario. The following inputs remain constant throughout all four (4) scenarios:

- Fire size and scenario;
- Rig geometry (cavity, room sizes, wall thicknesses and window sizes);
- Materials adopted.

The following will be variable based on each scenario:

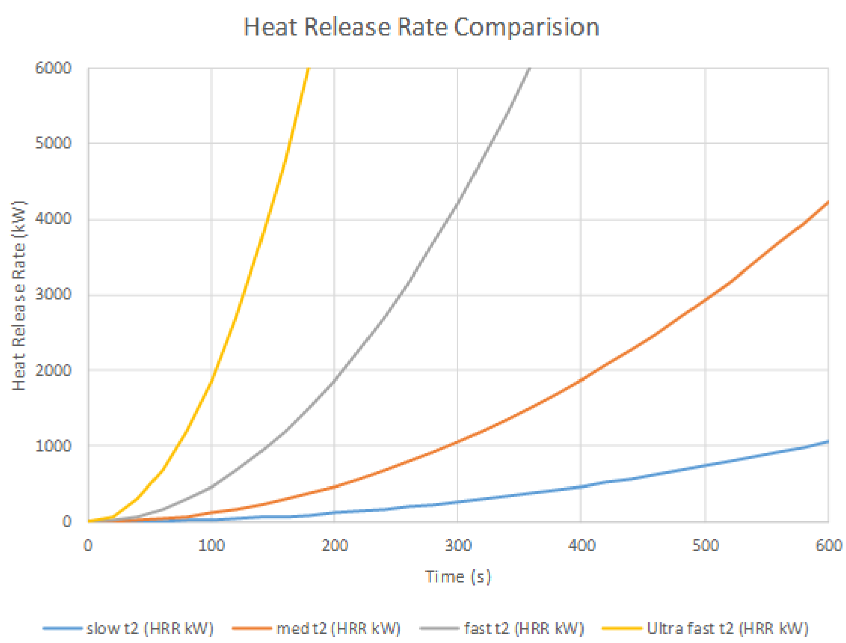
- Façade attachment (i.e. PE Cladding and Solid Aluminium Cladding)
- Installation of cavity barrier.

3.3.1 Fire Size and Scenario:

Fire growth occurs according to the calculation performed by the software. The FDS solves the equations governing the simulated system and provides graphical and numerical data for each scenario. The models show a simplified representation of the analysed cases.

The proposed fire scenario consists of a non-sprinkler protected residential fire, which comprises a fuel controlled medium t^2 fire in the SOUs in the fire room as per the SP Fire 105 test, the fire source w. A flashover fire will be considered for scenarios relating to fire resistance of construction elements where applicable, as shown below in Graph 1.

Typical fuel loads likely to be encountered in the residential areas include furniture, upholstery, rubbish bins and electrical equipment. Medium t^2 growth rates have been reported to be representative of the above fuel loads.



Graph 1 – Comparison of heat release rates of various design fires

With reference to Figure 25, the fire modelled in the FDS simulations for the four scenarios described above, is a fire with a Heat Release Rate (HRRPUA) of 2,000 kW/m^2 with a ramp up time of 420 s (7 minutes). These inputs are consistent with the parameters set out in the SP Fire 105 Test as shown in the tests by (Babrauskas, 1996).

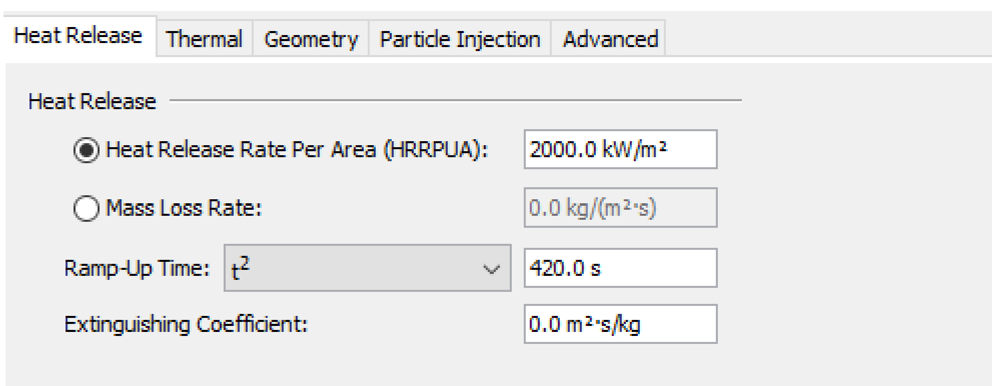


Figure 25 – FDS Properties of fire source

The fire source consisted of a 500 mm x 2000 mm x 100 mm Heptane Tray, that was situated in an independent Fire Room with dimensions of 3200 mm x 1700 mm and a height of 1300 mm. The Fire Room is located below at the bottom of the rig with an opening of 1100 mm high and 3000 mm wide for the fire to spread from.

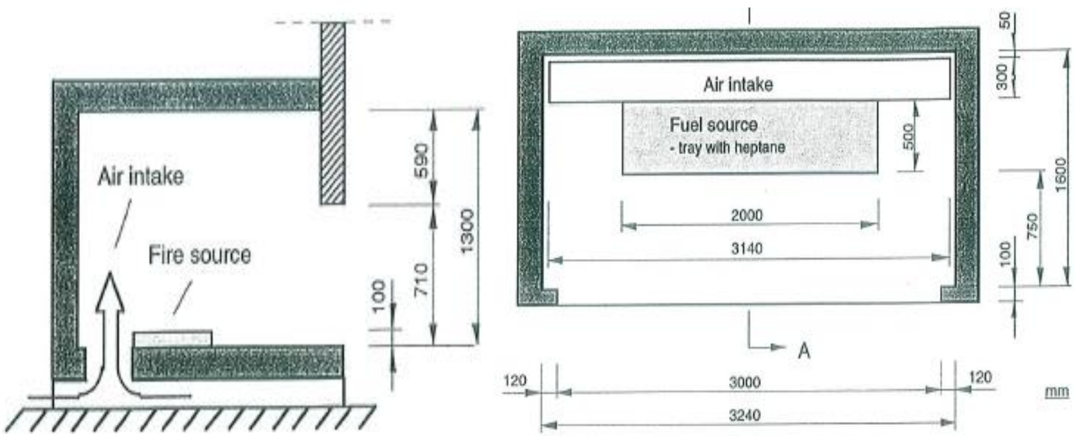


Figure 26 – Extract from the SP Fire 105 Test showing fire source and air intake (Swedish National Testing and Research Institute, 1985)

3.3.2 Rig geometry

With reference to Figure 27, the overall dimensions of the rig that was modelled based on the SP Fire 105 rig is as follows:

- Total height of rig: 6.7 m
- Total width of rig: 4 m
- Total depth of rig: 1.6 m
- Room heights: Fire Room – 1.3 m, Level 1 – 2.7 m, Level 2 – 2.7 m.
- Window openings: located on Level 1 (Room 1) and Level 2 (Room 2): each window is 1.5 m wide x 1.2 m high.
- Fire Room opening: 3 m x 0.7 m
- Fire room air intake opening: 3.1 m x 0.3 m
- Cavity width: 100 mm
- Façade thickness: 0.005 m (i.e. 5 mm)
- Slab thickness between levels: 0.2 m thick
- External wall thickness (i.e. wall cladding is attached to): 0.2 m

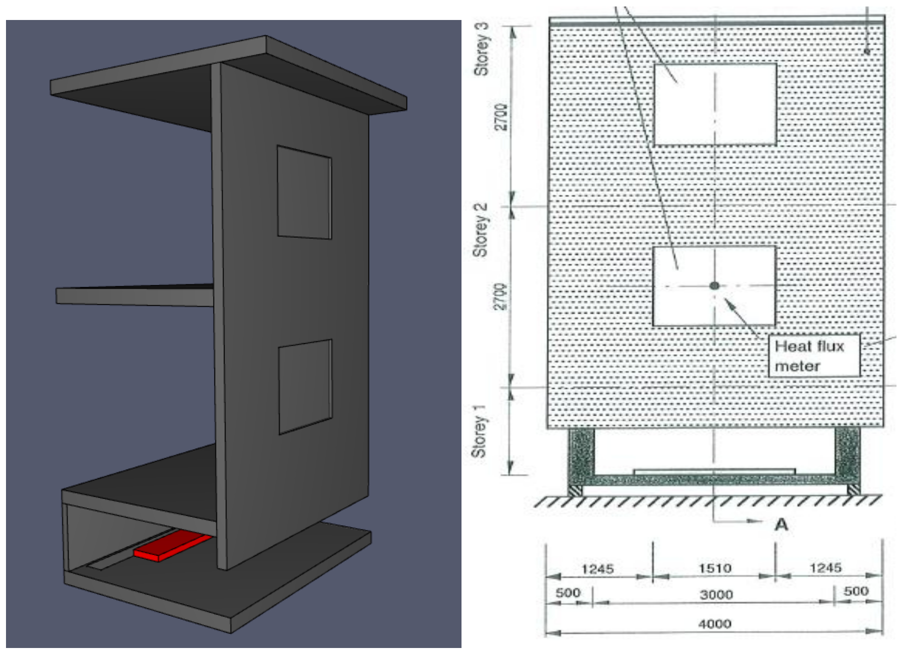


Figure 27 – Rig Dimensions based on SP Fire 105 Test

3.3.3 Materials Adopted

For the model scenarios described above in Section 3.3, the following materials were used. Note that for any material not specified in the SP Fire 105 Test, an assumption was made based on standard construction practice:

- **Flooring**: Concrete slab, the material was defined in FDS with the following thermal properties as per FDS inputs given in the library (National Institue of Standards and Technology, 2019):
  - Density: 2280 kg/m^3
  - Specific Heat: 1.04 kJ/(kg*K)
  - Conductivity 1.8 W/(m*K)
- **External wall** as described in the SP Fire test will be light weight concrete as such the above thermal properties were used.
- **Burner**: Heptane burner was used with the following properties as per (Swedish National Testing and Research Institute, 1985)

    - HRRPUA: 2000 kW/m^2
    - T^2 fire with a ramp up time of 420 s
- **Façade 1**: Polyethylene core cladding, the 3 mm polyethylene core comprised the following thermal properties:
    - Density: 400 kg/m^3
    - Specific Heat: 1.76 kJ/(kg*K)
    - Conductivity: 1.9E5 W/(m*K)
    - Heat of Combustion: 46,000 kJ/kg
- **Façade 2:** Solid Aluminium, 5 mm solid Aluminium was used on 2 of the 4 models simulated, with the following thermal properties:
    - Density: 2969 kg/m^3
    - Specific Heat: 0.921 kJ/(kg*K)
    - Conductivity: 226.0 W/(m*K)
    - Heat of Combustion: 3100 kJ/kg

3.3.4 Composite Cladding

The two different types of cladding materials observed in the modelling comprises non-combustible solid aluminium that is 5 mm thick and a composite cladding material with a 99% Polyethylene core that is a total of 5 mm thick, the material properties are derived from the QLD Cladding Register as shown in Appendix B.

McLaggan et al. has compiled a Cladding Materials Library with the assistance of The University of Queensland and the Department of Housing & Public Works which tested several cladding elements. The aim of this database was to provide information on different cladding materials in terms of their composition and flammability as individual components, and which may be used to perform hazard analysis. The properties of PE cladding and aluminum cladding was derived from this research using their website claddingmaterialslibrary.com - (McLaggan, 2019).

According to the information provided by the Database, a cladding sample with a Polyethylene core of 99% was extrapolated and the following results included:

Material ID: ACP03

Material type: Aluminium composite panel with a core consisting of polyethylene (PE).

Polymer: Polyethylene (99%)

Additives (fire retardants, fillers or traces of inorganic elements): Calcium (1%), traces of other elements (<1%)

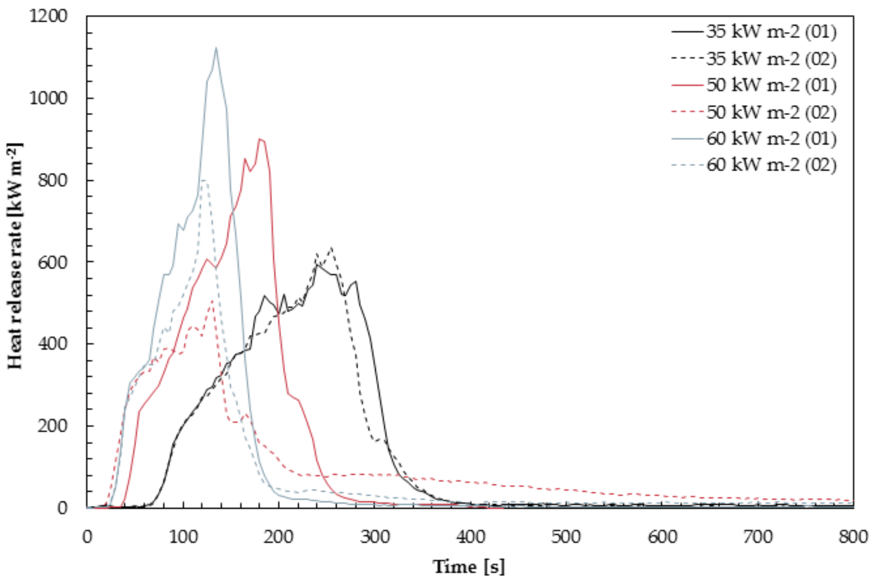
Core thickness: 2.86mm

Thickness of single metal skin: 0.5mm

Figure 28 – ACP 03 of the University of QLD database comprising 99% PE ACP

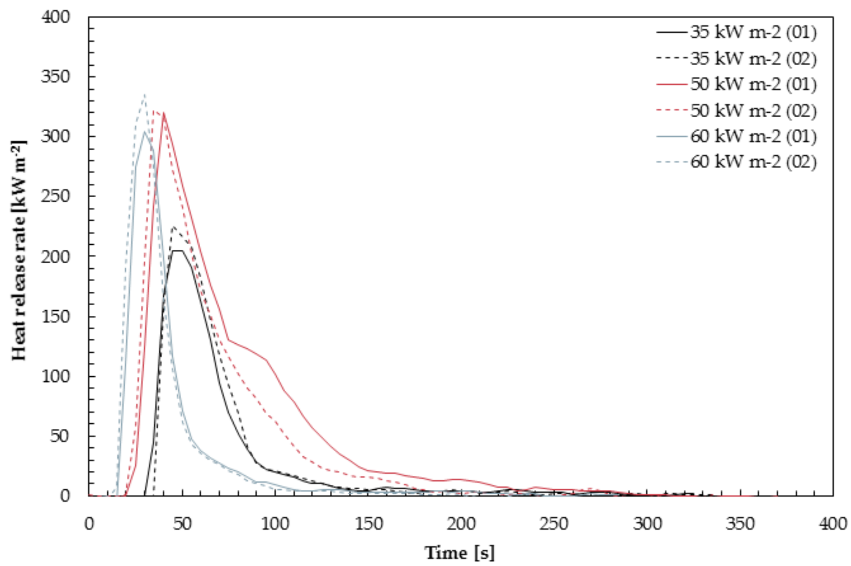
The ignition temperature was given as 398°C.

With reference to Graph 2, the heat release rate of the different samples is shown at different levels of heat flux. As can be seen the HRR rise is quite significant.



Graph 2 – Heat release rate per unit area over time for samples tested at different heat fluxes

As a comparison to the above, the heat release rate of a predominately non-combustible product such as the honeycomb aluminium ACP is shown below in Graph 3. The amount of heat released is significantly lower than the 99% PE Core ACP (i.e. 1100 kW/m^2 vs 350 kW/m^2 respectively).



Graph 3 – Heat release rate per unit area over time for samples tested at different heat fluxes

With reference to the above the cladding material simulated is in line with the properties provided in the QLD Cladding Database for the cladding known as ACP03.

The second type of façade simulated is a solid aluminium wall with similar properties to the honeycomb cladding known as ACP 10 in the database.

3.3.5 Cavity Barriers

In a lot of buildings that contain cladding as a decorative or protective lining on the façade the building external wall will have a cavity generally between 50 – 100 mm wide. This is due to the method cladding is fixed to the building, which is either mechanically fixed or tape fixed. The most common form of fixing is mechanical fixing (cassette system) as this provides a form of structural support. With this type of fixing a cavity of at least 50-100 mm is required for the stud work to fit, this is because aluminium vertical and horizontal stud work is fixed to the external wall, which the cladding is attached to.

As such a cavity is present between the cladding and the building external wall or concrete floor (suspended slab) slab edge. As discussed in Section 2.4, a cavity can create a wind tunnel for a fire to flow into, as such a cavity barrier mitigates the passage of fire and smoke and in turn mitigates fire spread.

In the models simulated a cavity of 100 mm is provided for all four (4) models, cavity barriers are provided in 2 of the models to show the impact cavity barriers have on a building with solid aluminium cladding and a building with PE cladding.

It has been shown that the temperature within the cavity in a cladding fire can exceed 800^{o}C (Anderson & R, 2013). The modelling conducted in this paper will try to demonstrate that the installation of cavity barriers will be effective in stopping the temperature from getting that high in a cladding fire.

With reference to Figure 29, a cavity barrier has been input into Model 1 and Model 3 along the slab edge of Level 1 and Level 2, the cavity barrier stretched from the slab edge to the backing of the attached cladding attachment. For the sake of modelling the cavity barrier is provided as an inert material, this is based on AS 1530.4 tests conducted on certain cavity barrier products out there in the market today such as the Bossfire Rainscreen Ventilated Façade Batts, where they have been tested for a fire resistance level of up to 2 hours when subjected to a standard fire curve (the same as the modelled scenarios). Since the 4 models simulated run for a maximum total of 15 minutes (900 s) each, an inert cavity barrier was deemed sufficient for acting as fire block.

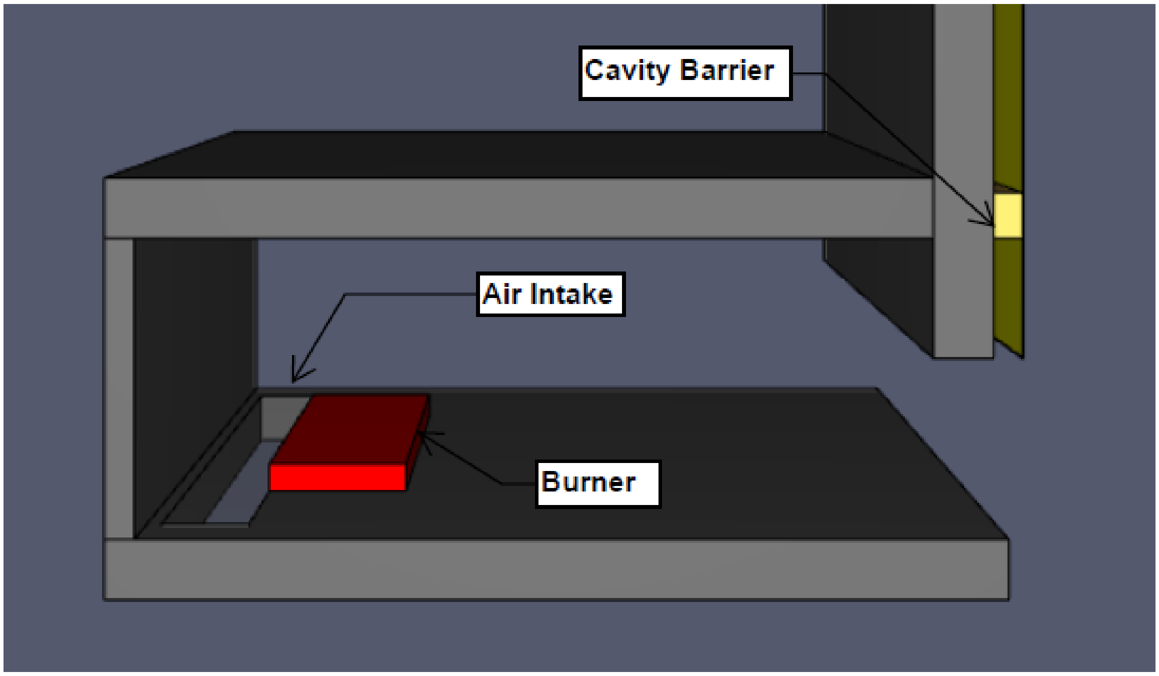


Figure 29 – Cavity barrier used in Model 1 and Model 3

3.3.6 Measuring Devices

In order to extrapolate results from the FDS simulations modelled, a number of devices have been positioned in each model. Since the design of the models in this report are based on the SP Fire 105 test. The inclusion of standard Thermocouples and Heat Flux devices have been input as per the standard as shown below in Figure 30 (Swedish National Testing and Research Institute, 1985); I.e. 1 heat flux device in the center of the first fictitious window and a temperature device directly below the eaves. In addition to the required devices, a thermocouple and heat flux device has been placed in the centerline within the cavity at intervals of 1,000 mm starting from the bottom of the external wall.

The intent of these devices is to show the temperature and heat flux of the cavity at different heights, this will provide an insight as to how the cavity barriers installed will impact on the cladding fires on a building with PE ACP (i.e. combustible cladding) and solid aluminium cladding (i.e. non-combustible cladding).

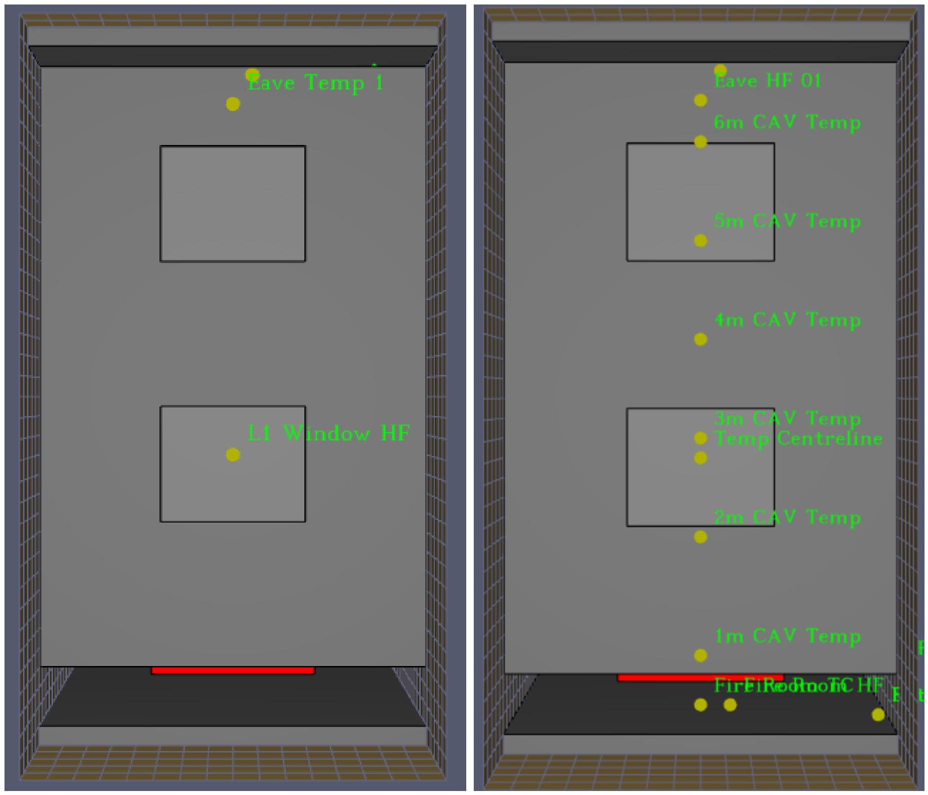


Figure 30 – Location of heat flux and thermocouple devices in the models simulated – left shows devices required by SP Fire 105, right shows additional devices placed

3.3.7 Mesh Inputs

With reference to Figure 31 and Figure 32, the mesh size and dimension used for all four models simulated are the same. The total number of cells equaled 52,800 with a cell size of 100 mm on the X-axis, 100 mm on the Y-axis and 96 mm on the Z-axis was used.

It is to be noted that three different meshes were created to simulate the model, this was done to reduce simulation time by deleting wasted space that is not required for the results. This mesh size used is considered large enough to facilitate the fire plume resulting from the system combustion. In the FDS guide (National Institue of Standards and Technology, 2019), a criterion for the quality of the mesh resolution is given for simulations involving buoyant plumes. It is assessed using the nondimensional D*/Δx ratio, where Δx is the size of the grid cells and D* the characteristic fire diameter. Following this expression, for the total HRR achieved numerically for the Heptane Tray and the tested system (maximum of Q = 7 MW), the adequate fine mesh size Δx to obtain reliable predictions of the radiative heat flux should be close to 130 mm. Since we used a mesh size of less than 130 mm accurate result predictions are expected to be simulated from the modelling conducted.

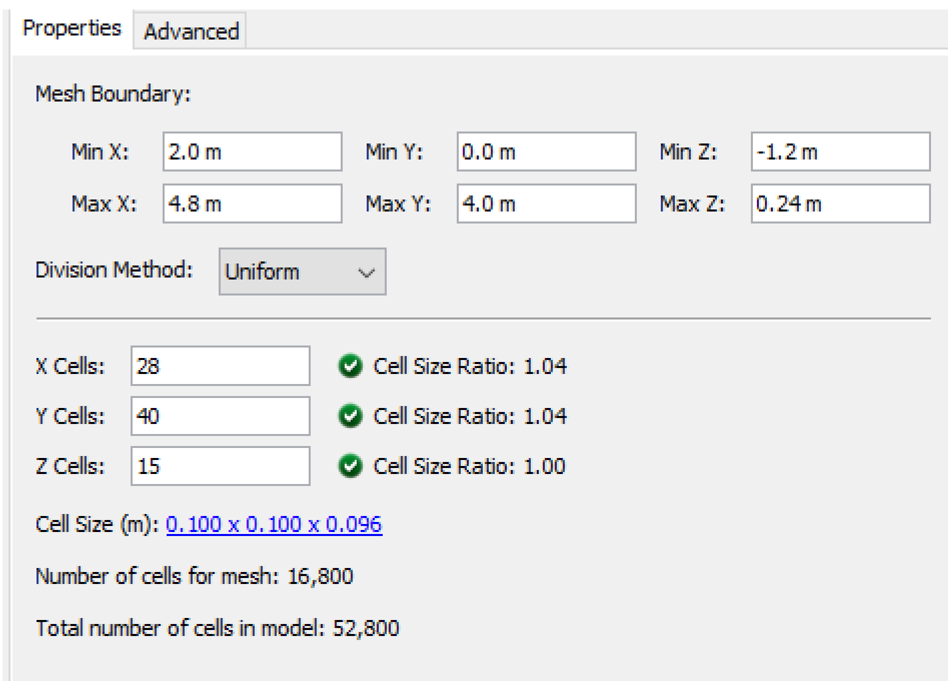


Figure 31 – Mesh size and dimension for Models 1 – 4

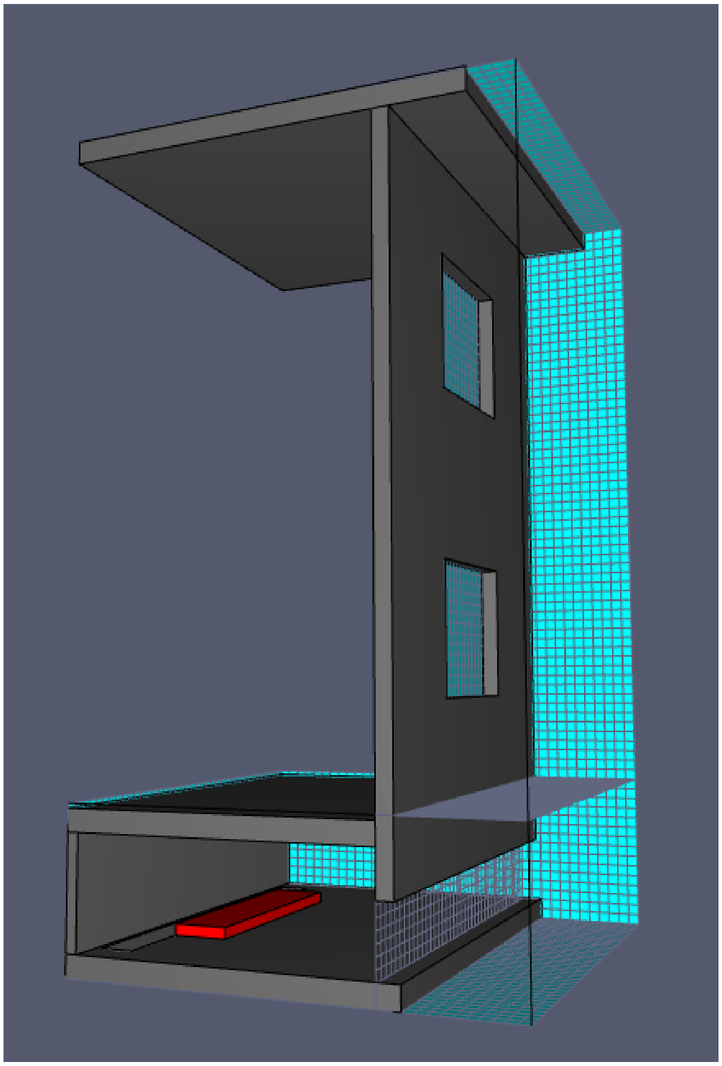


Figure 32 – Mesh used for modelling

3.3.8 Simulation Time

The simulation time was selected based on the SP Fire 105 test run times of between 15 – 20 minutes, as such the base model (i.e. SP Fire 105 replica) was simulated for 900 s (15 min) while the other four (4) variable models were simulated for 1,200 s (20 min).

4 CHAPTER IV: MODELLING RESULTS

This section describes the results of the five (5) models simulated as described above in Section 3, which are as follows:

1) **Base Model** – The first model simulated comprises the validation model that will be compared to that of the tests results found in the (Babrauskas, 1996), (Anderson & McNamee, 2012) and (Anderson, et al., 2016) research papers.
2) **Model 1** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITH** the installation of a cavity barrier at the slab edge, the façade attachment comprises aluminium composite panel with Polyethylene (PE) combustible cladding.
3) **Model 2** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITHOUT** the installation of a cavity barrier at the slab edge, the façade attachment comprises aluminium composite panel Polyethylene (PE) combustible cladding.
4) **Model 3** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITH** the installation of a cavity barrier at the slab edge, the façade attachment comprises non-combustible construction.
5) **Model 4** - A fire within a room spreading onto a 100 mm wide cavity without any thermal insulation, **WITHOUT** the installation of a cavity barrier at the slab edge, the façade attachment comprises non-combustible construction.

The FDS models will be validated against the performance criteria set out in the SP Fire 105 test which is as follows – each models results will be compared to that of the criteria shown in Table 7 below to determine if the performance of the test conducted will pass or fail and to determine the validity of the FDS simulations as well as a comparison will be made between the results of existing research papers that have simulated the SP Fire 105.

Table 7 - Performance criteria of the SP Fire 105 test used as validation technique

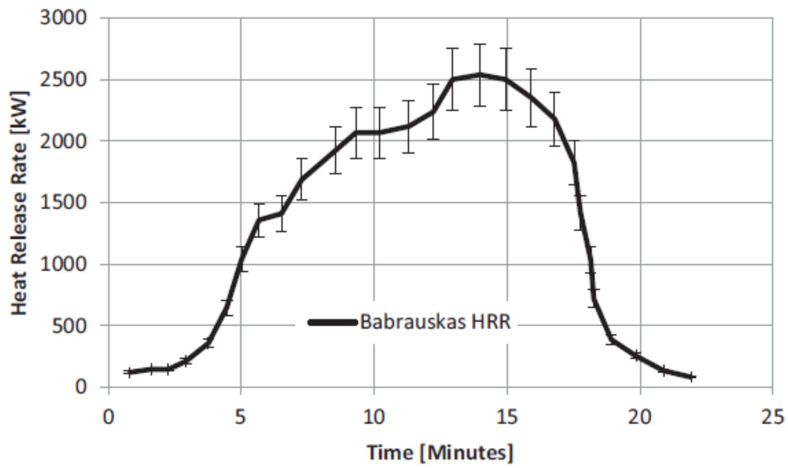
Performance Criteria	
External Fire Spread	No fire spread >4.2 m above opening (bottom of fictitious window) Temps at the eave must not exceed 500°C for more than 2 min or 450°C for more than 10 min for buildings > 8 stories high or hospitals, heat flux <80 kW/m^2, 2.1 m above opening
Internal Fire Spread	No fire spread > 4.2 m above opening (bottom of second storey fictitious window)
Burning Debris	To be reported but criteria not specified by standard
Mechanical Behavior	No large pieces are permitted to fall from the building

4.1 Base Model – Validation Scenario

The first model simulated was conducted as a validation model to compare the results against that of the SP Fire 105 test, the results of the modelling conducted were assessed against the performance criteria set out in the SP Fire 105 test as well as the test results undertaken by Johan Anderson and Robert Jansson McNamee in the research paper (Anderson & McNamee, 2012), (Anderson, et al., 2016) and (Babrauskas, 1996).

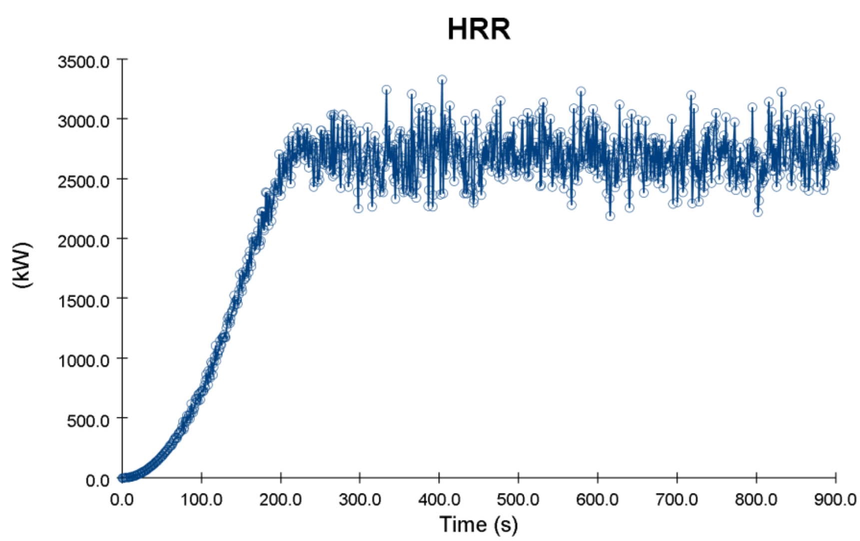
4.1.1 Heat Release Rate

The Heat Release Rate (HRR) was assumed to be consistent with the HRR taken shown in the experimental large scale tests conducted by Babrauskas in the research paper referenced (Babrauskas, 1996). With reference to Graph 4, the maximum HRR is approximately 3,000 KW at a time of 12 minutes.



Graph 4 – HRR as shown in the Babrauskas 1996 research paper

With reference to Graph 5, the HRR achieved in the base model scenario conducted reached a peak of 3,000 KW at 400 seconds, this is consistent with the above HRR taken as such the model in terms of HRR can be validated as being accurate with the comparison results.



Graph 5 – Heat release rate of the fire from the base model conducted

4.1.2 Flame Height

The performance criteria states that there should be no fire spread greater than 4.2 m above bottom of the Level 1 window:

With reference to Figure 33, the flame height of the real-life test rig is shown and is compared to the base modelling simulated. The flame height is taken at 7 minutes once the flame is fully combusted.

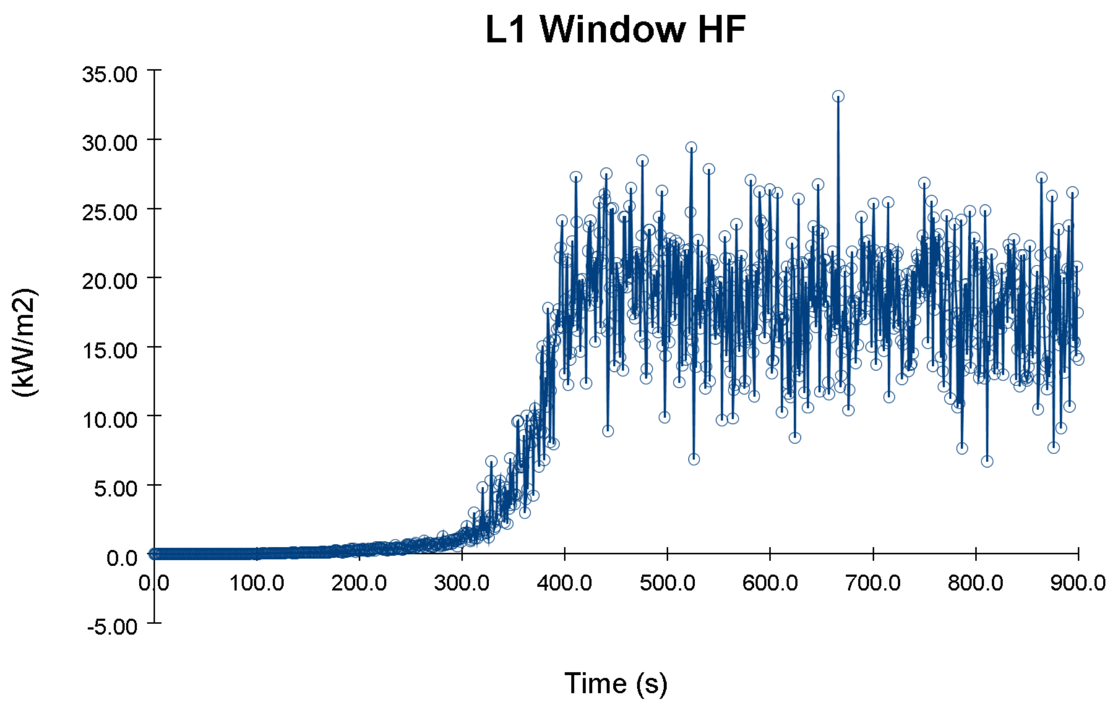
The height of the flame was measured using the functions provided in the FDS software and it was shown that the height in the base model with no combustible cladding installed did not exceed 4.2 m above the bottom of the first window, as such meets the performance criteria of the SP Fire 105 test standard.

It was observed that the flame from the ground floor of the fire room reached a maximum height of approximately 3.95 m as shown below on the right.

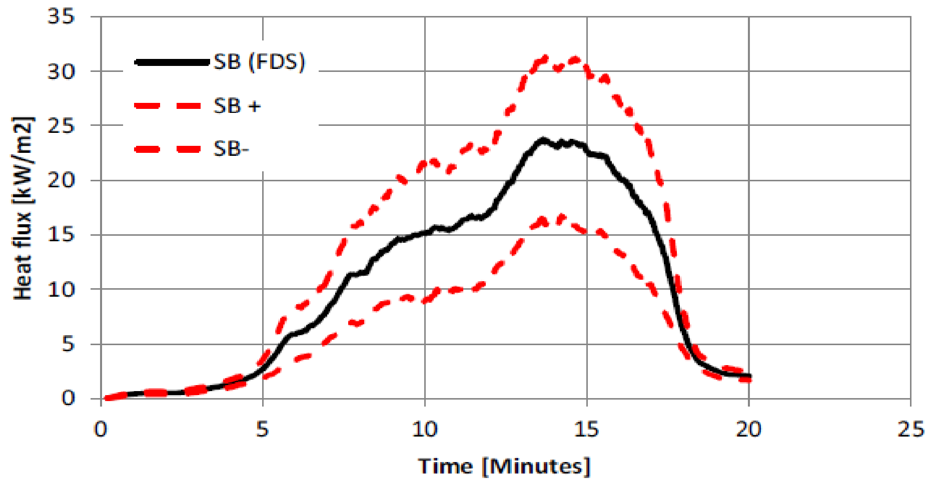
Figure 33 – Flame height on the left of real test vs modelling simulated

4.1.3 Heat Flux

With reference to Graph 6, the heat flux achieved at the fictitious window on Level 1 as per the heat flux device input, required by the SP Fire 105 test provides a maximum Heat Flux of between 20 - 30 kW/m^2 over the duration of the 900 seconds the fire was simulated for. As a comparison for validation purposes the graph shown in Graph 7, provides the heat flux achieved in the same location in the tests conducted in the (Anderson, et al., 2016) paper dated May 2016, which range from 15 kW/m^2 – 30 kW/m^2.



Graph 6 – Heat flux at the window of Level 1 against time of fire



Graph 7 – Heat flux achieved at the center of the fictitious window taken from the validation SP Fire 105 test paper

4.1.4 Temperature

With reference to Figure 34 , the maximum temperature reached was 1000°C. This temperature was reached at around the 420 second mark, it is to be noted that the temperature within and directly outside the fire room stayed between 700 – 800°C as per the yellow and green thermographic diagram extracted from the FDS simulation. with reference to the graphs shown in Graph 8 and Graph 8, the temperature taken from the thermocouples located directly below the eaves is taken and compared with the temperature results from the validation paper being used.

It can be observed that the maximum temperature sustained just below the eaves within the base model is 359°C at 420 seconds (7 minutes), in comparison the temperature shown in the comparison paper as per the SP Fire 105 standard test was a maximum of 220°C at 15 minutes. The performance criteria states that the temp must not exceed 500°C at the eaves, as such is in line with the standard criteria.

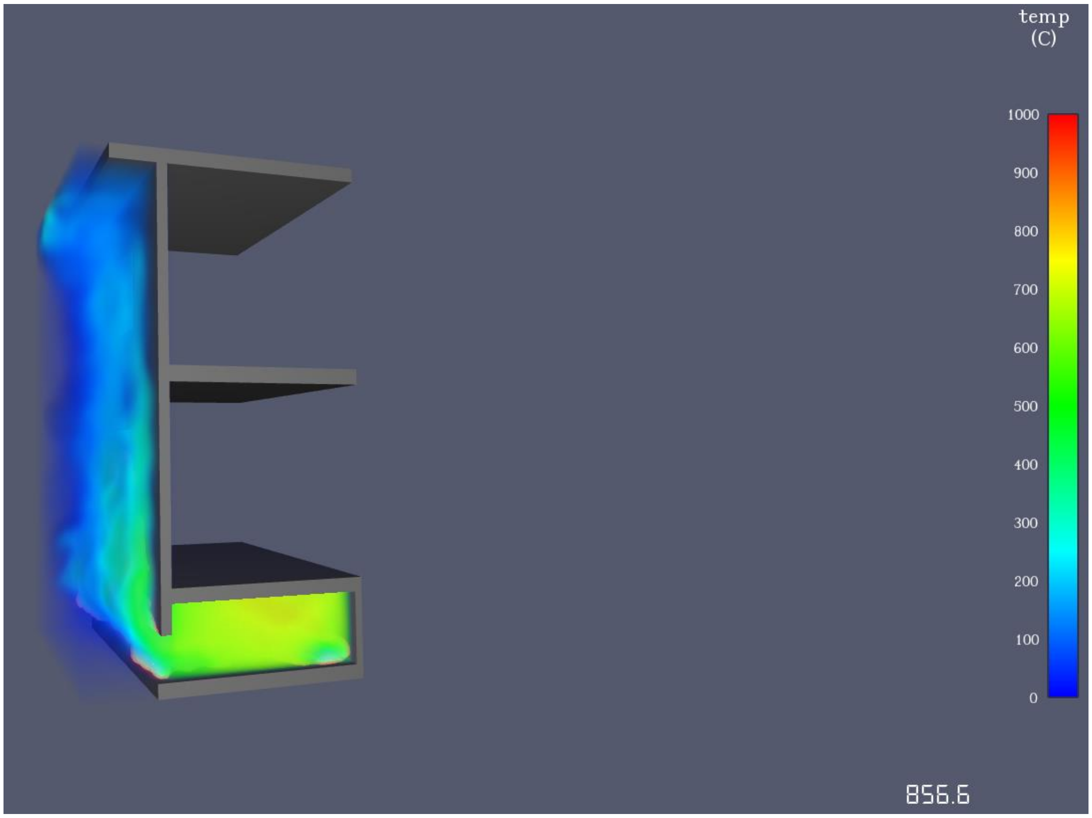
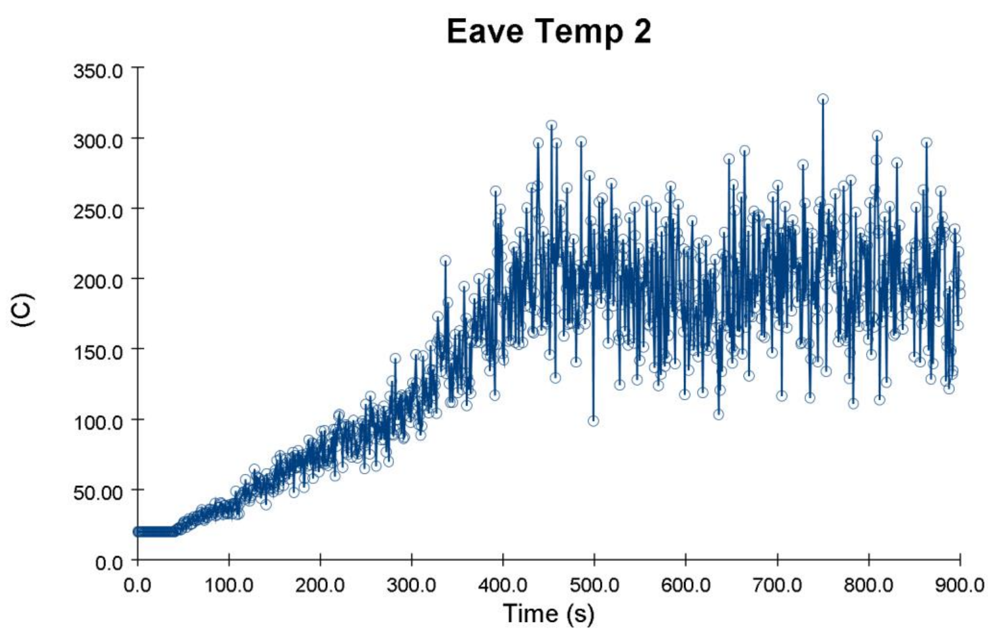
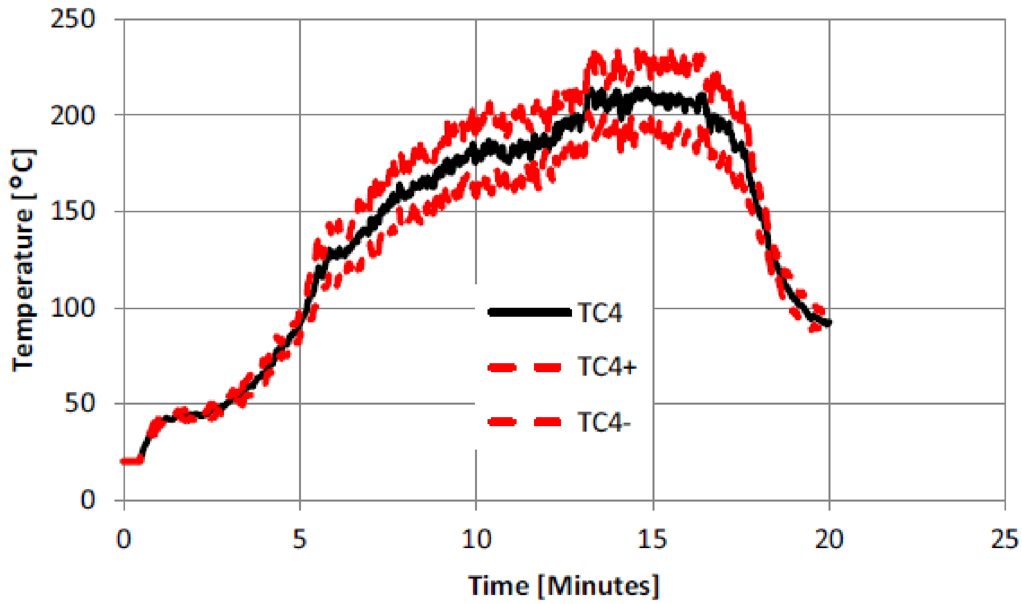


Figure 34 – Snapshot of Model 2 thermographic showing maximum temperature reached



Graph 8 – Graph showing temperature of the thermocouples located directly below the eaves

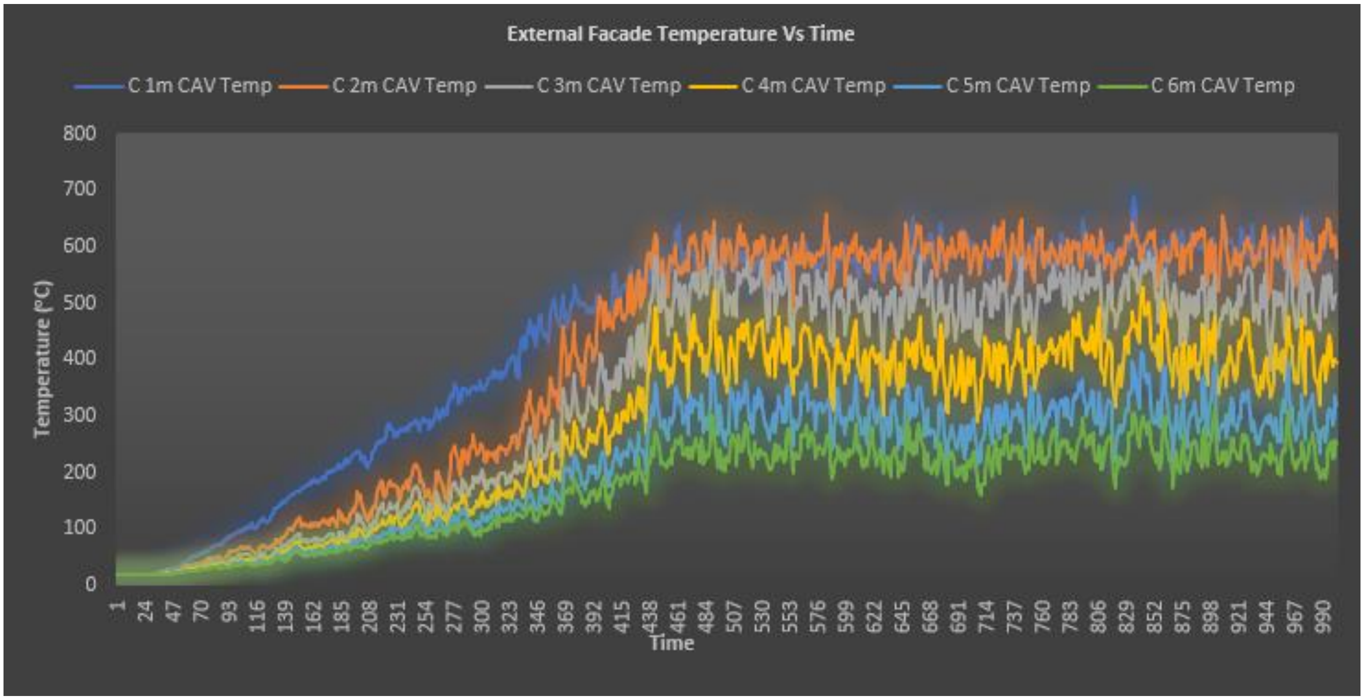


Graph 9 – Temperature of the eave thermal couples taken from the validation SP Fire 105 test

The temperature of the external façade was documented via the placements of thermocouple at every meter above the Fire Room finished floor level (FFL) - i.e. at 1 m, 2m, 3m, 4m, 5m and 6m. With reference to the Graph 10, it was observed that the temperature external temperature of the test rig gradually decreased with height. Maximum temperature was reached at around 500 seconds, at 1m and 2m heights the temperature was ~650 – 690°C. The maximum temperatures directly outside the external wall at different heights was recorded as follows for the base model simulated:

Table 8 – Maximum temperatures at the eaves at 1 m intervals directly outside the facade

Eave	Facade 1m	Facade 2m	Facade 3m	Facade 4m	Facade 5m	Façade 6m
Maximum Temperature						
359°C	688°C	658°C	616°C	529°C	412°C	312°C



Graph 10 – External façade temperature of the Base Model shown at every 1m up to 6m at 900 s

4.2 Modelling Scenario 1 – PE, Cavity Barrier

Model 1 comprised the use of combustible PE cladding with the installation of cavity barriers, the following results are extrapolated from the FDS simulation.

4.2.1 Flame Height

With reference to Figure 35, the height of the flame sustained in Model 1 consisted of a full height flame, at the 600 second mark the entire façade caught alight and the flame was increased to the height of the entire building (i.e. 6.8 m) from the floor of the Fire Room. It is noted that the performance criteria set out in SP Fire 105, requires the maximum height above the first window not to exceed 4.2 m above the first window opening, with the model simulation it was observed that the flame height exceeded the maximum height criteria, as such fails the SP Fire 105 test criteria.

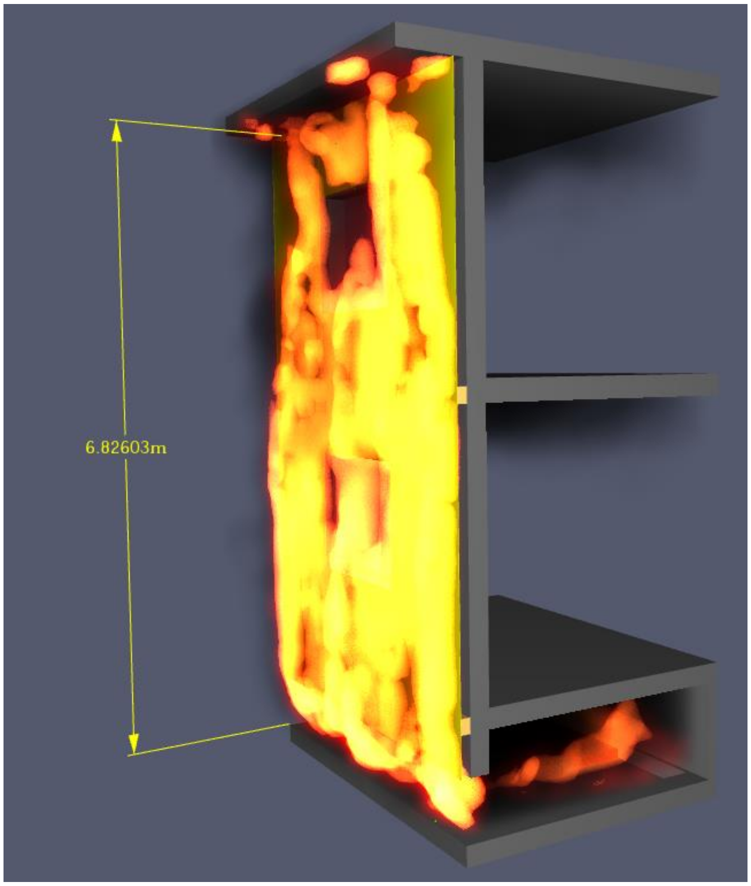
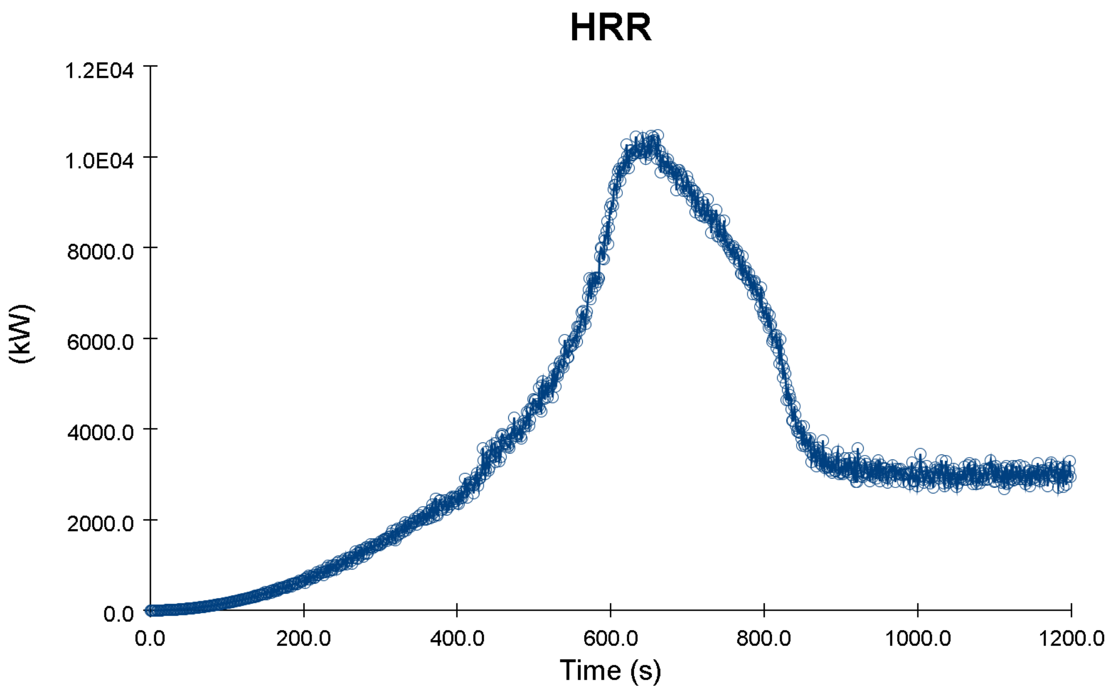


Figure 35 – Snapshot from the modelling showing height of the flame

4.2.2 Heat Release Rate

The maximum heat release rate of approximately 10 MW was reached after 650 s of run time, after which the cladding started to burn away as shown below in the below graph. Resulting in the heat release rate (HRR) to drop gradually back down to 3 MW, which is the HRR of the fire set up in the modelling simulation as per the SP Fire 105 test (i.e. Heptane Tray with 2MW HRRPUA) – it is to be noted that there was no suppression input placed on the Heptane tray, as such the fire stayed constant at 3MW and did not die down.



Graph 11 – Graph showing heat release rate of the fire

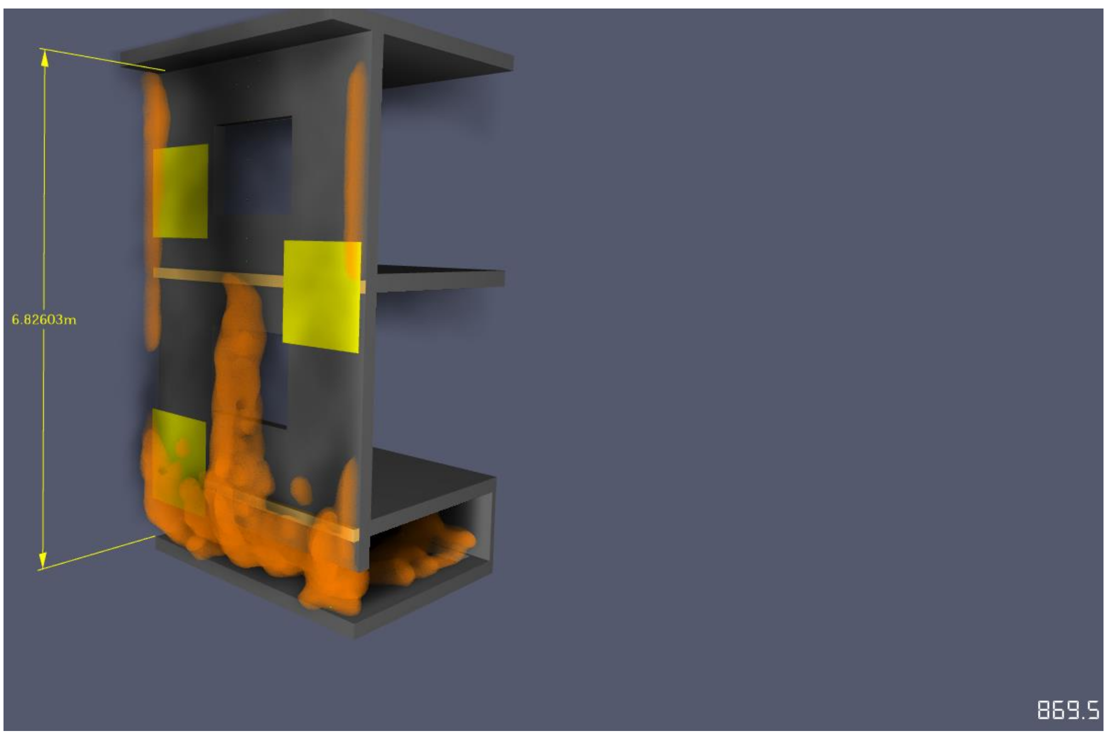


Figure 36 – Snapshot of Model 1 showing cladding burning away after 420 seconds

4.2.3 Temperature

With reference to Figure 37, the maximum temperature reached was 820^{o}C, the temperature started to reduce gradually as the cladding started to burn off the building. At 915 seconds all the cladding with the exception of one panel located at the bottom left corner had burnt off and the height of the flame was reduced from the full height of the building to approximately 3.5 m high.

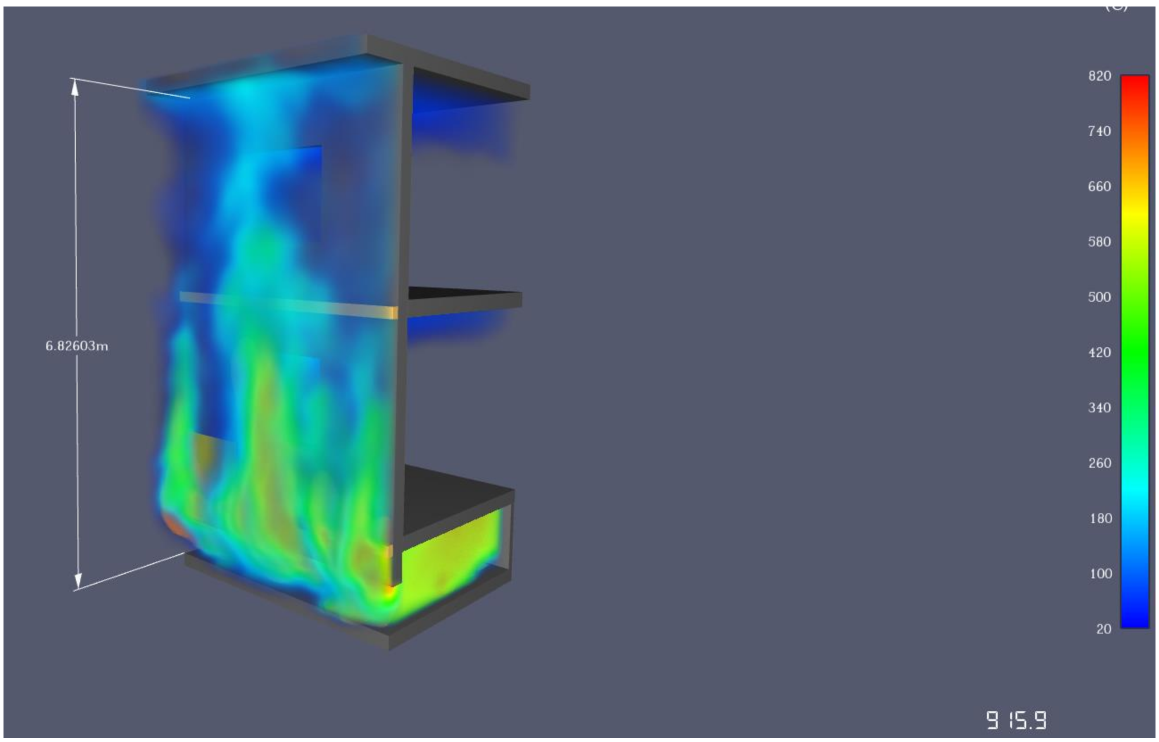
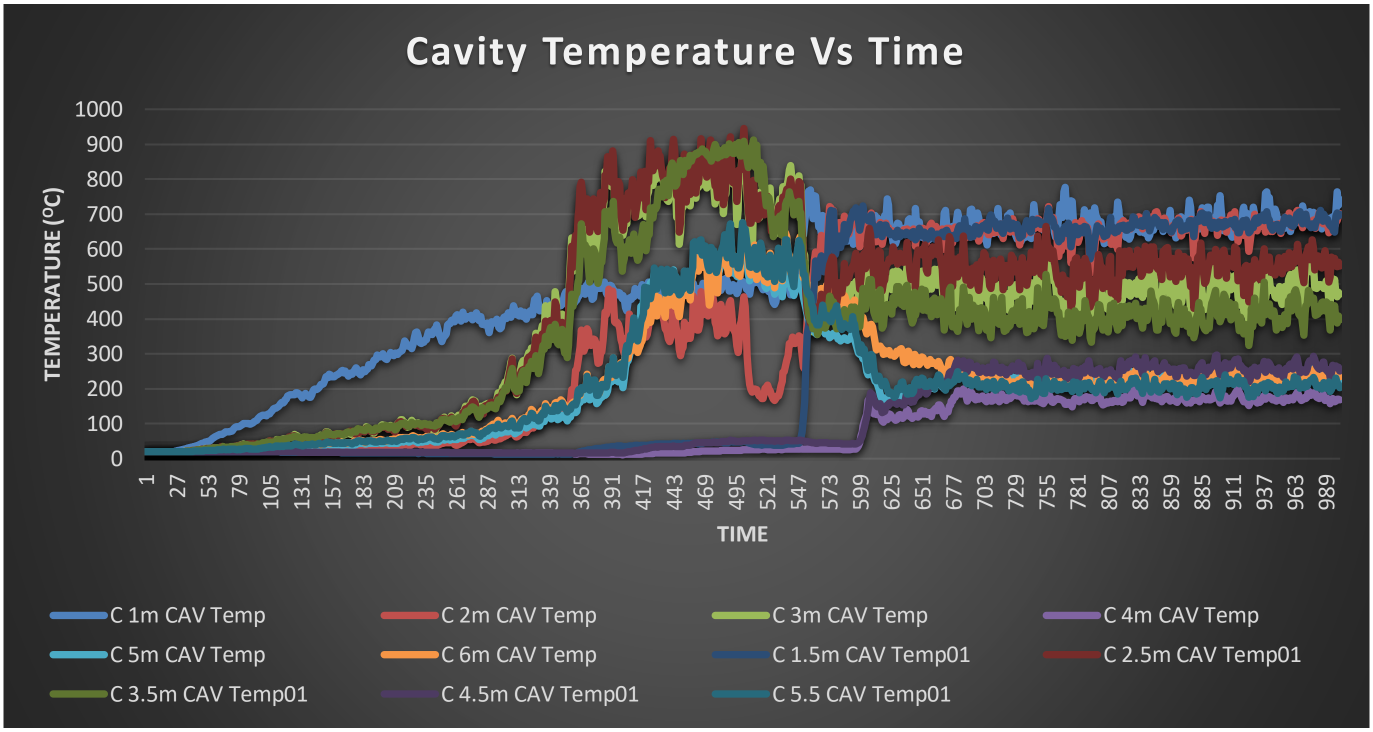


Figure 37 – Snapshot of Model 1 thermographic showing maximum temperature reached

The temperature of the cavity is shown in the graph plotted below. The temperatures stayed relatively low within the cavity at heights of 1.5m, 4m and 4.5m before the cladding had started to burn away around the 500 second mark. The temperature of the cavity where the windows is located was high due to the opening and the cavity barriers not providing much effect.



Graph 12 – Graph showing temperature of the cavity at different heights of Model 1

The below table shows the maximum temperatures reached at the eaves (i.e. 869°C) and at 1 m intervals within the cavity (i.e. 1m, 2m, 3m, 4m, 5m, & 6m). It is observed from these results that the cavity barriers had a slight effect on the temperature however, once the cladding started to burn away the temperature within the cavity increased to over 600°C. It is noted that the performance criteria of SP 105 requires the eave temperature to be below 420°C, in this case a temperature of 869°C was achieved, as such would not pass this criteria and in turn fail the large scale test.

Table 9 – Maximum temperatures at the eaves and 1 m intervals within the cavity

Eave	Cavity 1m	Cavity 2m	Cavity 3m	Cavity 4m	Cavity 5m	Cavity 6m
Maximum Temperatures						
869°C	776°C	721°C	927°C	202°C	611°C	647°C

4.2.4 Heat Flux

With reference to Figure 38, the heat flux achieved at the window of level 1 within the cavity was a maximum of 100 kW/m^2, in comparison to that of the base model with no cavity barriers which was 30 kW/m^2. It is to be noted that the heat flux started to reduce after 520 seconds once the cladding started to burn away.

It is noted that the heat flux within the cavity and away from the window openings is much lower than that off the heat fluxes achieved along the window openings. It was observed that the heat flux within the cavity was significantly reduced due to the installation of cavity barriers. However, the since the cladding burn away relatively quickly the cavity barriers will not be of a benefit.

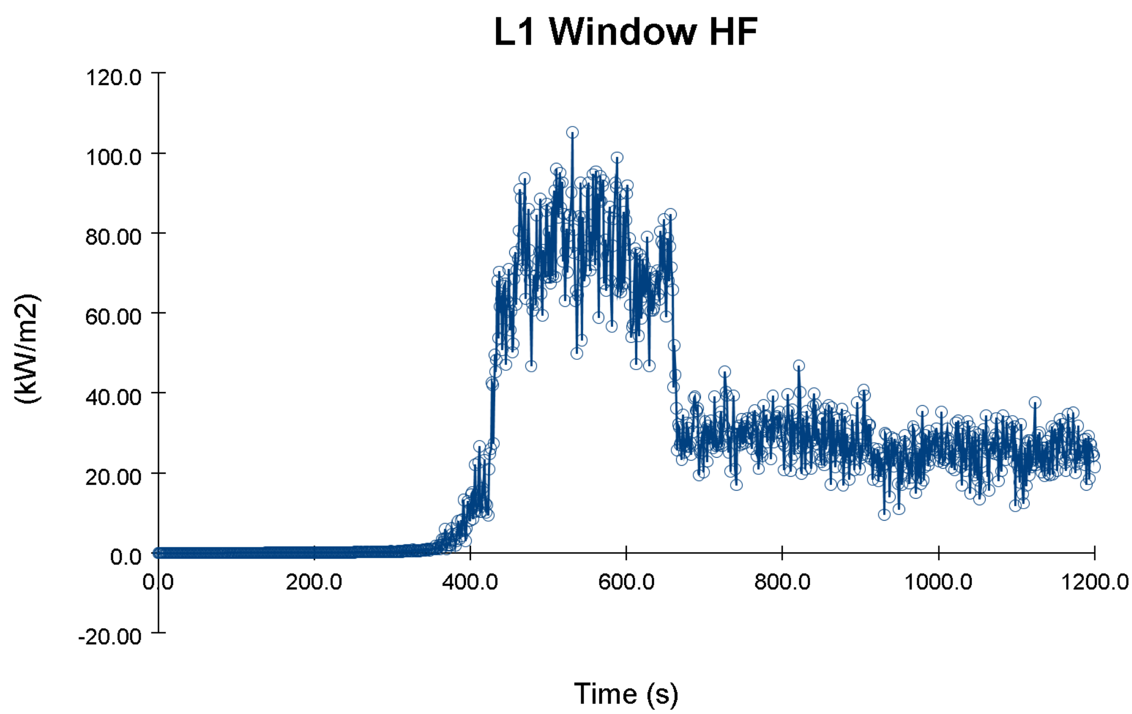


Figure 38 – Heat flux at the window of Level 1 against time of fire

4.3 Modelling Scenario 2 – PE, No Barrier

Model 2 comprised the use of combustible PE cladding without the installation of cavity barriers, the following results are extrapolated from the FDS simulation.

4.3.1 Flame Height

With reference to Figure 39, the height of the flame sustained in Model 1 consisted of a full height flame, at the 600 second mark the entire façade caught alight and the flame was increased to the height of the entire building (i.e. 6.8 m) from the floor of the Fire Room. It is noted that the performance criteria set out in SP Fire 105, requires the maximum height above the first window not to exceed 4.2 m above the first window opening, with the model simulation it was observed that the flame height exceeded the maximum height criteria, as such fails the SP Fire 105 test criteria.

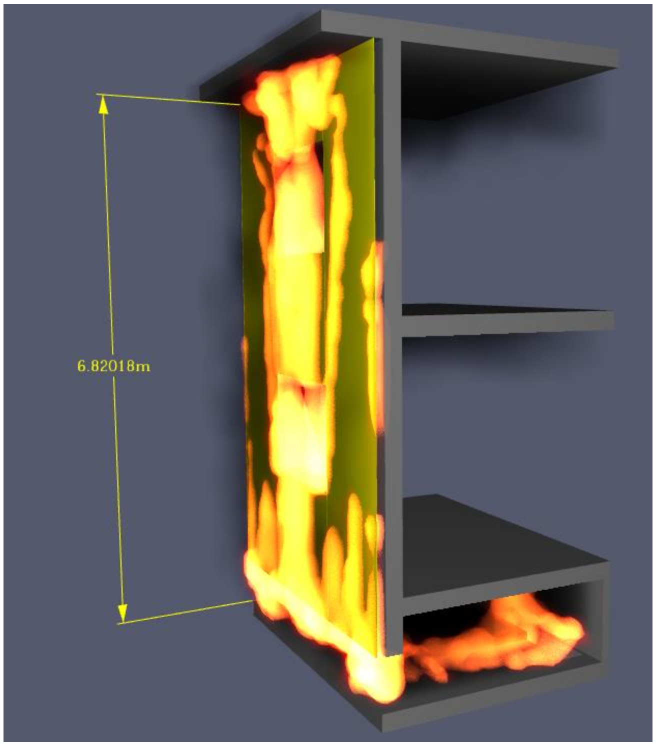


Figure 39 – Snapshot from the modelling 2 showing height of the flame

4.3.2 Heat Release Rate

The maximum heat release rate of approximately 7 MW was reached after 650 s of run time, after which the cladding started to burn away as shown below in. Resulting in the heat release rate (HRR) to drop gradually back down to 3 MW, which is the HRR of the fire set up in the modelling simulation as per the SP Fire 105 test (i.e. Heptane Tray with 2MW HRRPUA) – it is to be noted that there was no suppression input placed on the Heptane tray, as such the fire stayed constant at 3MW and did not die down.

Also to note, is that the fire room was included into the mesh of the simulation and as such the fire stayed at the maximum constant HRR, without the inclusion of additional fuel loads such as cladding after they have burnt off.

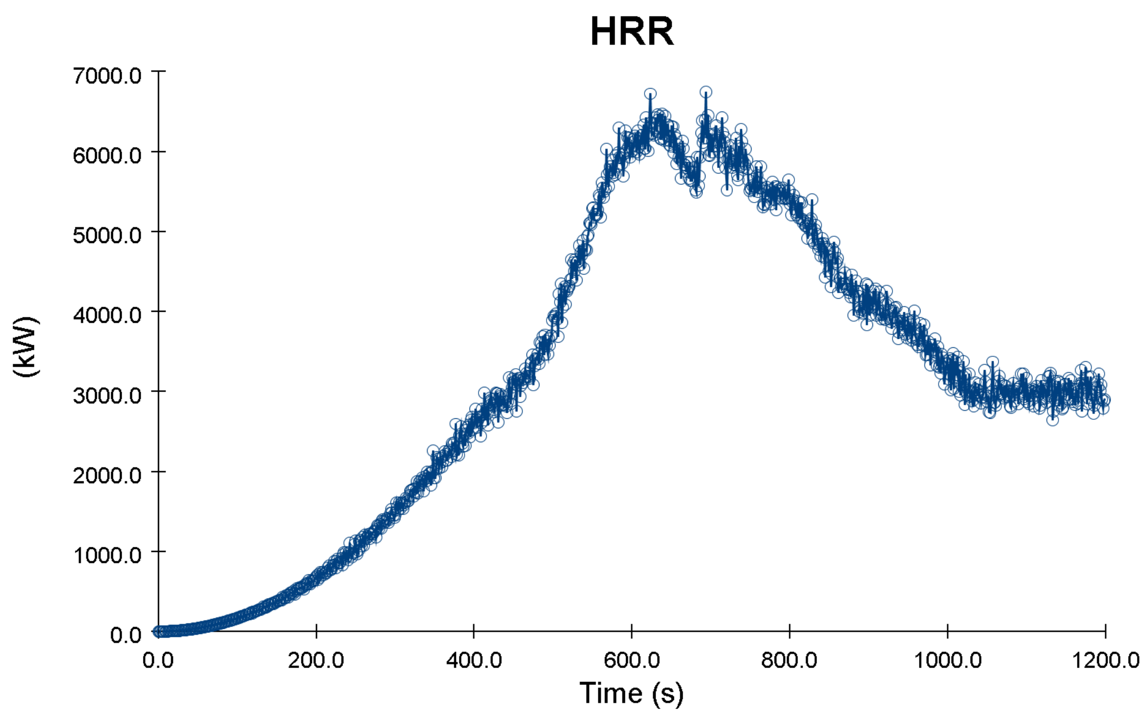


Figure 40 – Graph showing heat release rate of the fire of Model 2

4.3.3 Temperature

With reference to Figure 41, the maximum temperature reached was 870^{o}C, the temperature started to reduce gradually as the cladding started to burn off the building. At 1000 seconds all the cladding pieces fell off with the exception of 1 pieces which remained for the duration of the simulation, this was located on the lower left corner.

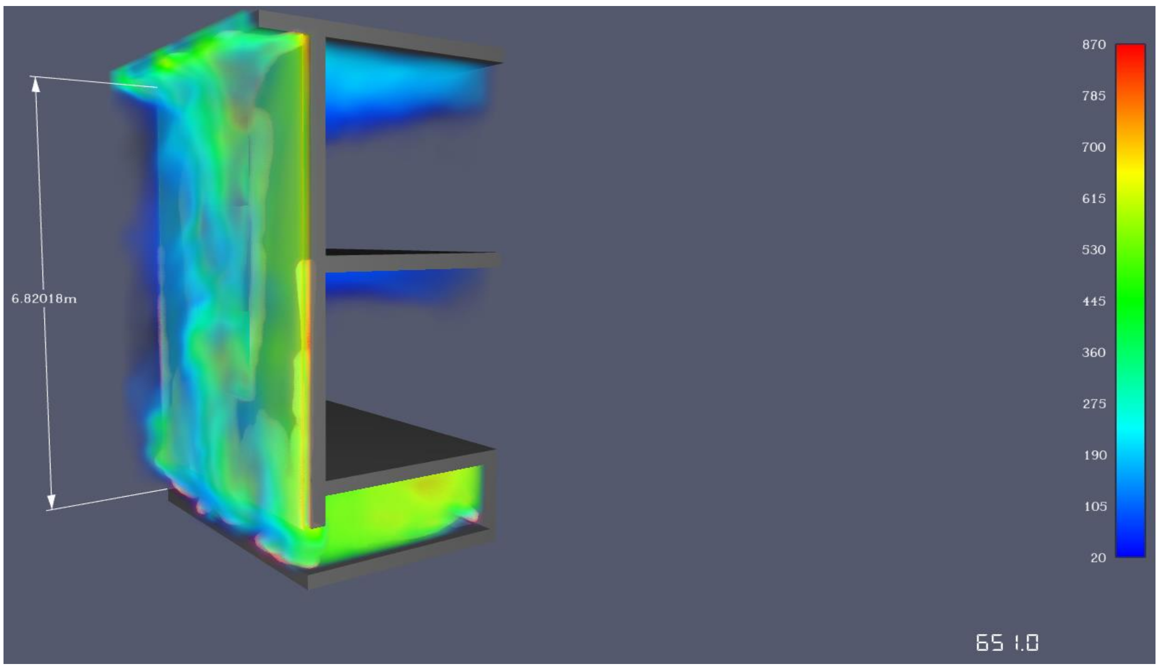
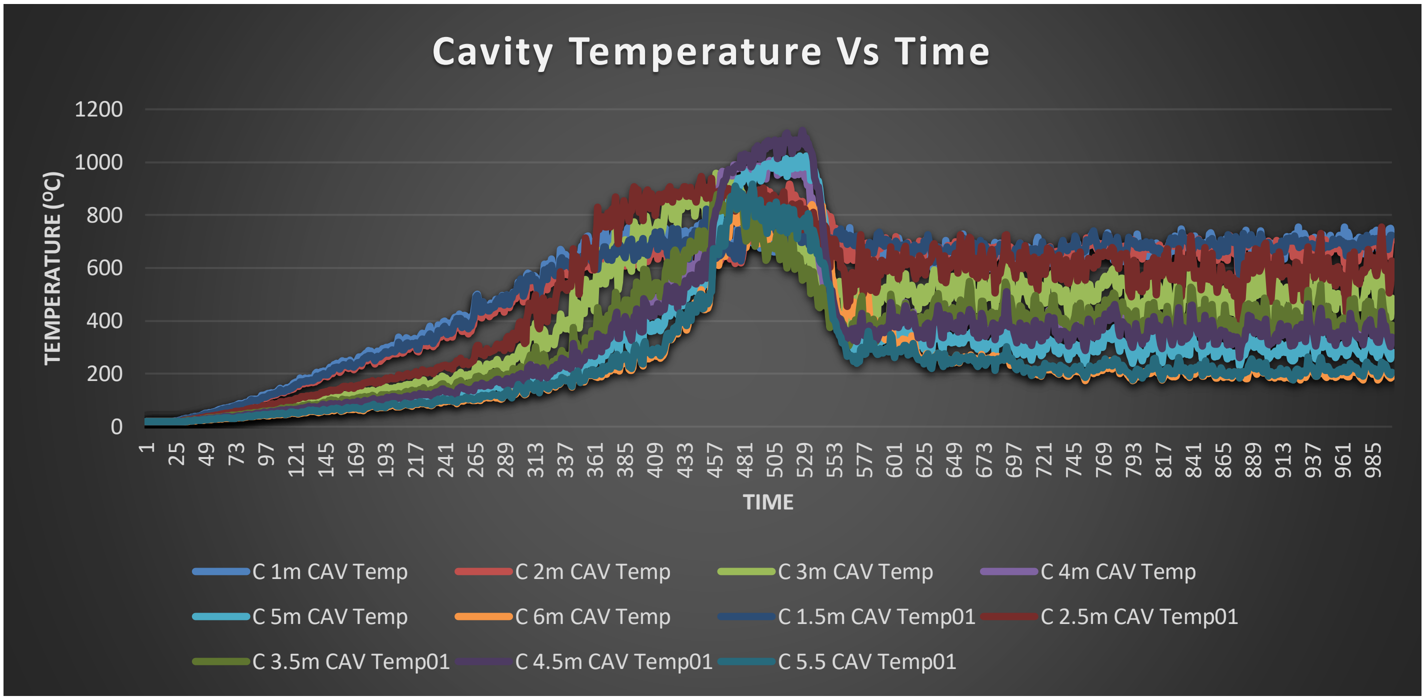


Figure 41 – Snapshot of Model 2 thermographic showing maximum temperature reached

The temperature of the cavity is shown in the graph plotted below. The temperatures throughout all devices input where consistent in terms of temperature rise and drop, it is noted that there is no cavity barriers installed in this model, and the results show that the temperature was lower at the higher levels. The temperature ramped up to a maximum point and was pretty similar throughout the entire façade, however once the cladding burnt off at approximately 550 – 600 second mark, the flame height dropped and the temperature throughout the lower levels was higher than the higher levels of the building.



Graph 13 – Graph showing temperature of the cavity at different heights of Model 2

The below table shows the maximum temperatures reached at the eaves (i.e. 950ºC) and at 1 m intervals within the cavity. Comparing these results with the ones in model 2, it can be concluded that the cavity barriers had a slight impact on cavity temperature before the cladding burnt off. However, once the cladding started to burn away the temperature of the external façade was relative to the height, as the flame height dropped due to the lack of fuel load burning. It is noted that the performance criteria of SP 105 require the eave temperature to be below 420ºC, in this case a temperature of 950ºC was achieved, as such would not pass this criterion and in turn fail the large-scale test.

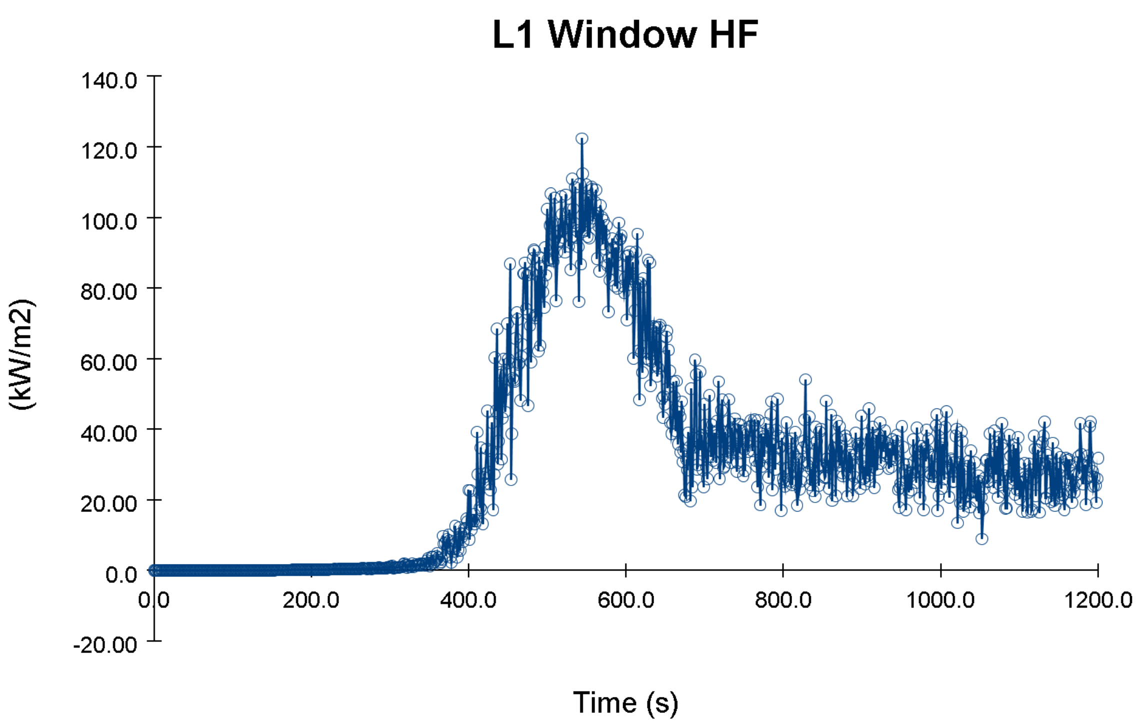
Table 10 – Maximum temperatures at the eaves and 1 m intervals within the cavity

Eave	Cavity 1m	Cavity 2m	Cavity 3m	Cavity 4m	Cavity 5m	Cavity 6m
Maximum Temperatures						
950ºC	832ºC	916ºC	960ºC	1007ºC	1024ºC	855ºC

4.3.4 Heat Flux

With reference to Graph 14, the heat flux achieved at the window of level 1 within the cavity was a maximum of 120 kW/m^2, in comparison to that of the PE cladding wall with no cavity barriers which was 100 kW/m^2. It is to be noted that the heat flux started to reduce after 550 seconds once the cladding started to burn away.

It was observed that the heat flux within the cavity showed a correlation between the height of the building as it is shown the heat flux located under the eaves reached around 80 kW/m^2 at 550 seconds.



Graph 14 – Heat flux at the window of Level 1 against time of fire

4.4 Modelling Scenario 3 – Solid Al, Barrier

Model 3 comprised the use of solid aluminium cladding with the installation of cavity barriers, the following results are extrapolated from the FDS simulation.

4.4.1 Flame Height

With reference to Figure 42, the flame height of the Model 3 is shown. The flame height is taken at 7 minutes once the flame is fully combusted. The height of the flame was measured using the functions provided in the FDS software and it was shown that the height in the base model with no combustible cladding installed did not exceed 4.2 m above the bottom of the first window, as such meets the performance criteria of the SP Fire 105 test standard. It was observed that the flame from the ground floor of the fire room reached a maximum height of approximately 3.4 m as shown below on the right.

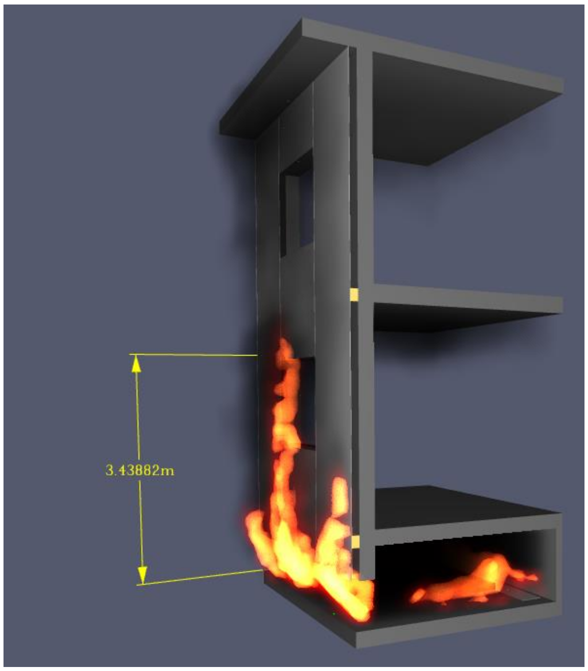


Figure 42 – Snapshot from the modelling 3 showing height of the flame

4.4.2 Heat Release Rate

The maximum heat release rate of approximately 3000 KW was reached after 400 s of run time, the HRR reached in the SP Fire 105 test used for validation was 2500 KW, although this is lower than the results generated, it is somewhat consistent considering the different variables that have taken place due to the modelling.

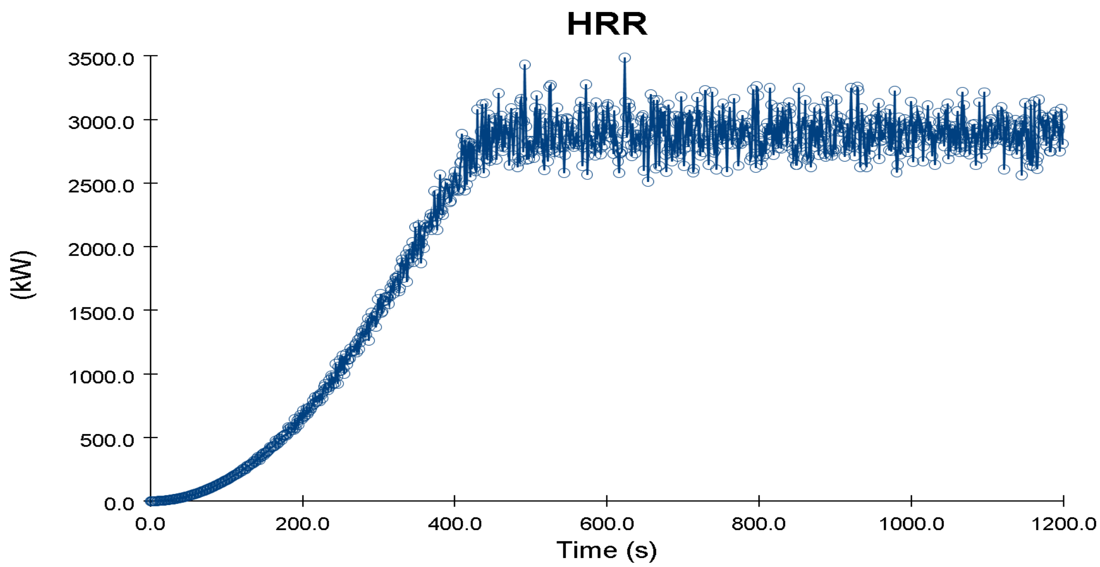


Figure 43 – Graph showing heat release rate of the fire of Model 3

4.4.3 Temperature

With reference to Figure 44, the maximum temperature reached was 770^{o}C and stayed constant throughout the duration of the simulation, this is because the façade did not burn away nor did it contribute to the fire load as it was non-combustible. The thermographic below shows that the cavity barrier done a good job in block the heat from passing through the cavity and entering the cavity. It is to be noted that the heat intensifies at the bottom of the cavity barrier as it does not disperse into the cavity and is slightly more concentrated at one point, this is shown by the red color gas directly below the first cavity barrier.

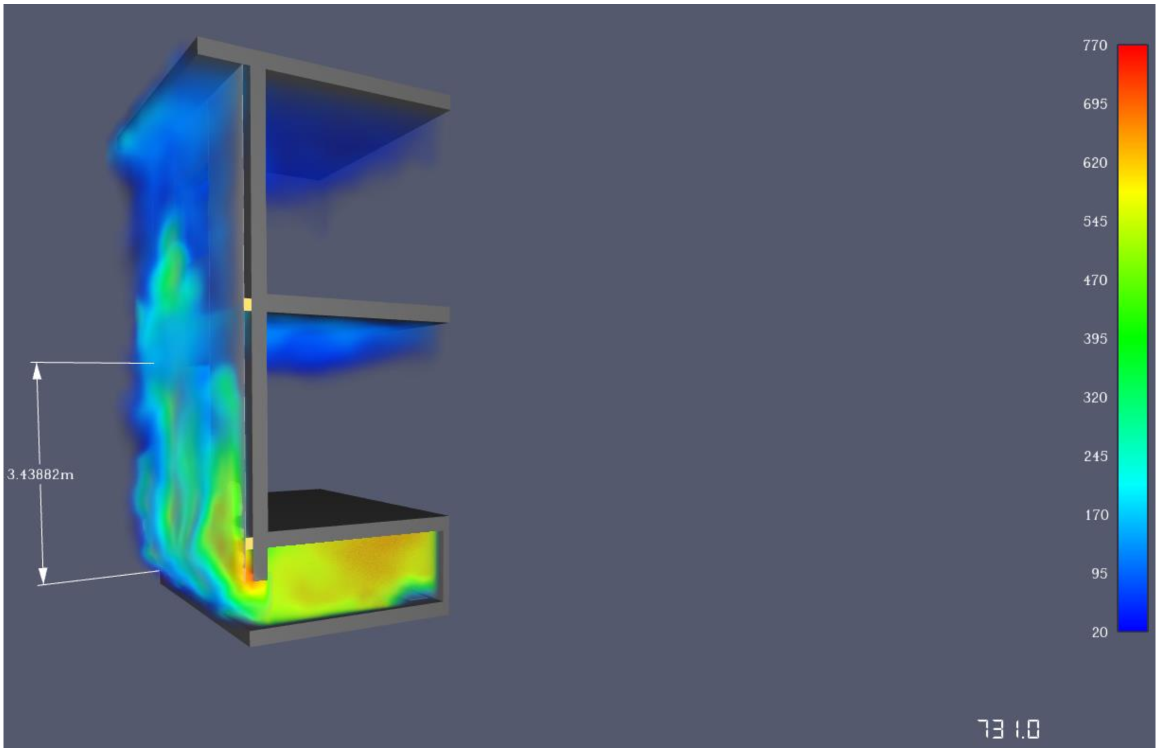
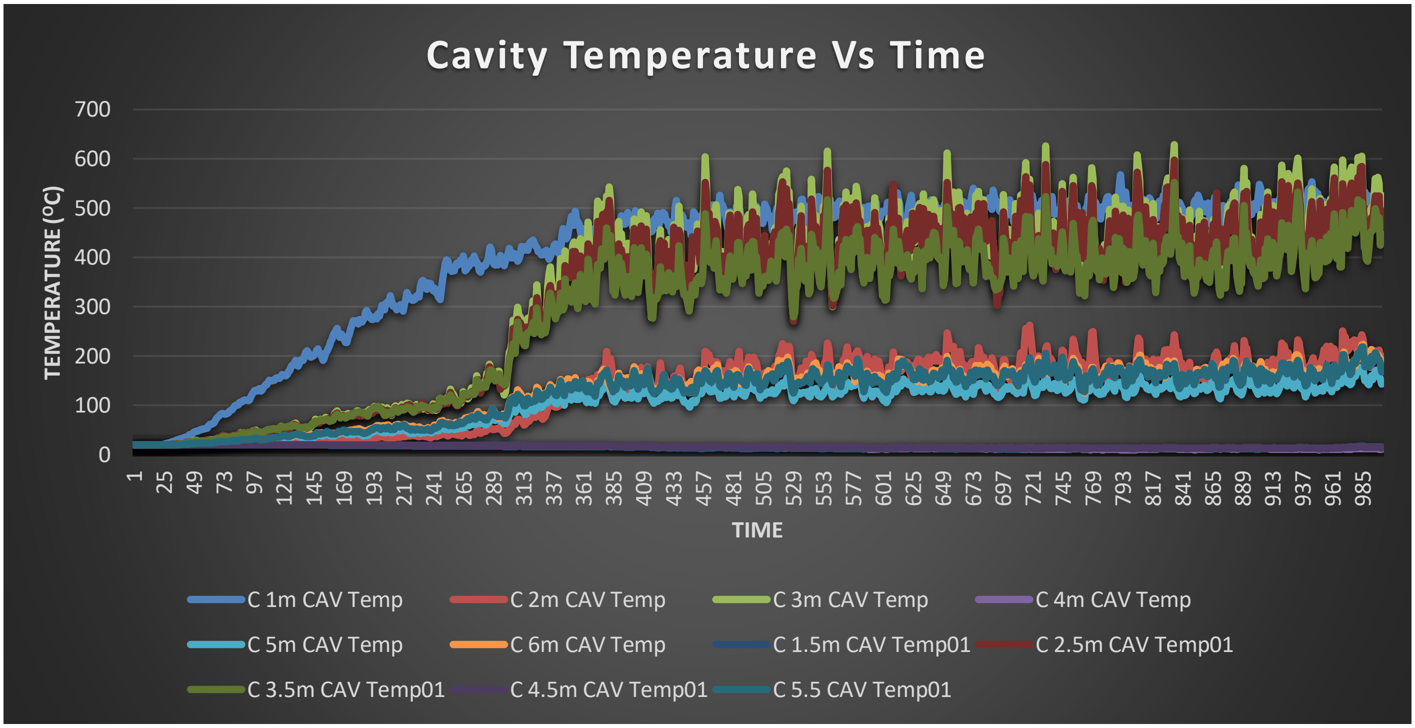


Figure 44 – Snapshot of Model 3 thermographic showing maximum temperature reached

The temperature within the cavity reached a maximum of approximately 628^{o}C at a height of 3m, this is due to the window opening and the fire source being directly outside of it. However, based on the maximum temperatures of the other devices placed within the cavity it can be concluded that the cavity barriers installed had a significant impact in reducing the cavity temperature and for the most part stayed below 250^{o}C.

Based on the temperatures plotted on the below graph the cavity barriers done a good job lowering the temperature within the cavity, and it is observed that the higher cavity temperatures of between 150-630^{o}C was due to the radiant heat entering into the cavity through the window openings. The temperatures at 4m and 4.5m stayed below 50^{o}C and between 5 and 6 m stayed below 250^{o}C.



Graph 15 – Graph showing temperature of the cavity at different heights of Model 3

Table 11 – Maximum temperatures at the eaves and 1 m intervals within the cavity

Eave	Cavity 1m	Cavity 2m	Cavity 3m	Cavity 4m	Cavity 5m	Cavity 6m
Maximum Temperatures						
316°C	567°C	262°C	628°C	20°C	178°C	224°C

4.4.4 Heat Flux

With reference to Figure 45, the heat flux achieved at the window of level 1 within the cavity was a maximum of 50 kW/m^2, which was reached momentarily at around 880 seconds, this was as a result of the radiant heat from the flame produced at the lower levels and not due to the fire entering the cavity.

The heat flux achieved within the cavity at the higher levels and away from the windows were all under 5kW/m^2. As such, the installation of cavity barriers on a solid aluminium façade significantly reduced the temperature and heat flux of the fire within.

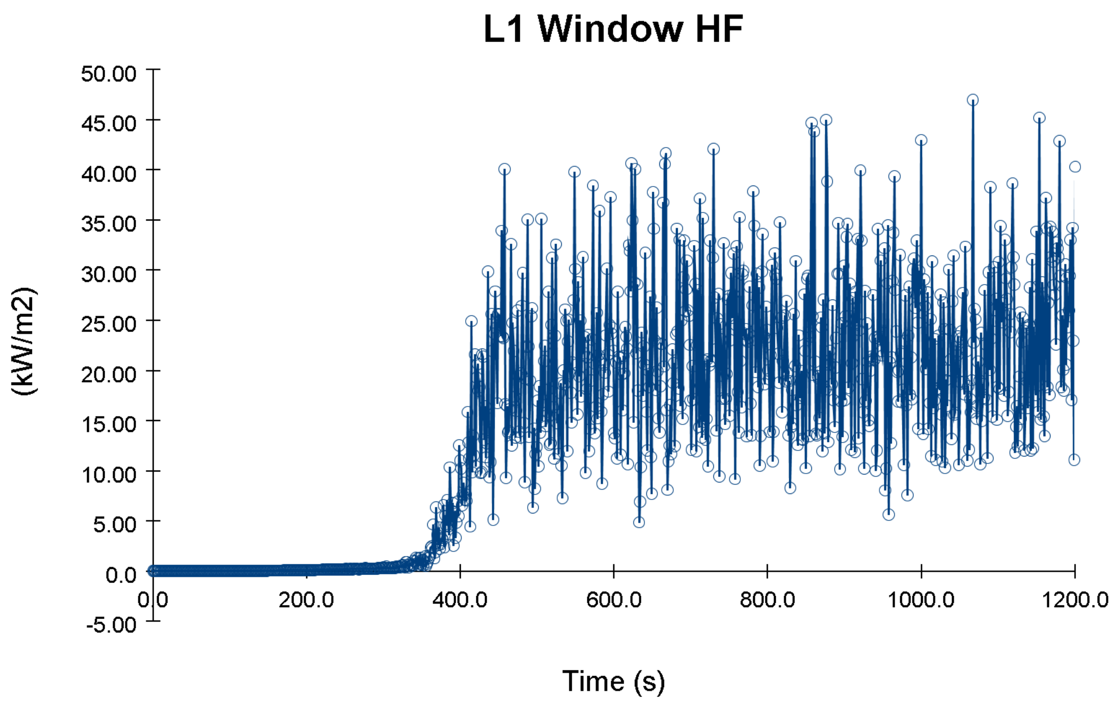


Figure 45 – Heat flux at the window of Level 1 against time of fire

4.5 Modelling Scenario 4 – Solid Al, No Barrier

Model scenario 4 was simulated to validate the results against the SP Fire 105 test, the following describes the results from the FDS simulation:

- Heat release rate as a function of time
- Heat flux as a function of time
- Temperature as a function of time.

The simulation was ended after 1200 s of run time, as the results stayed constant.

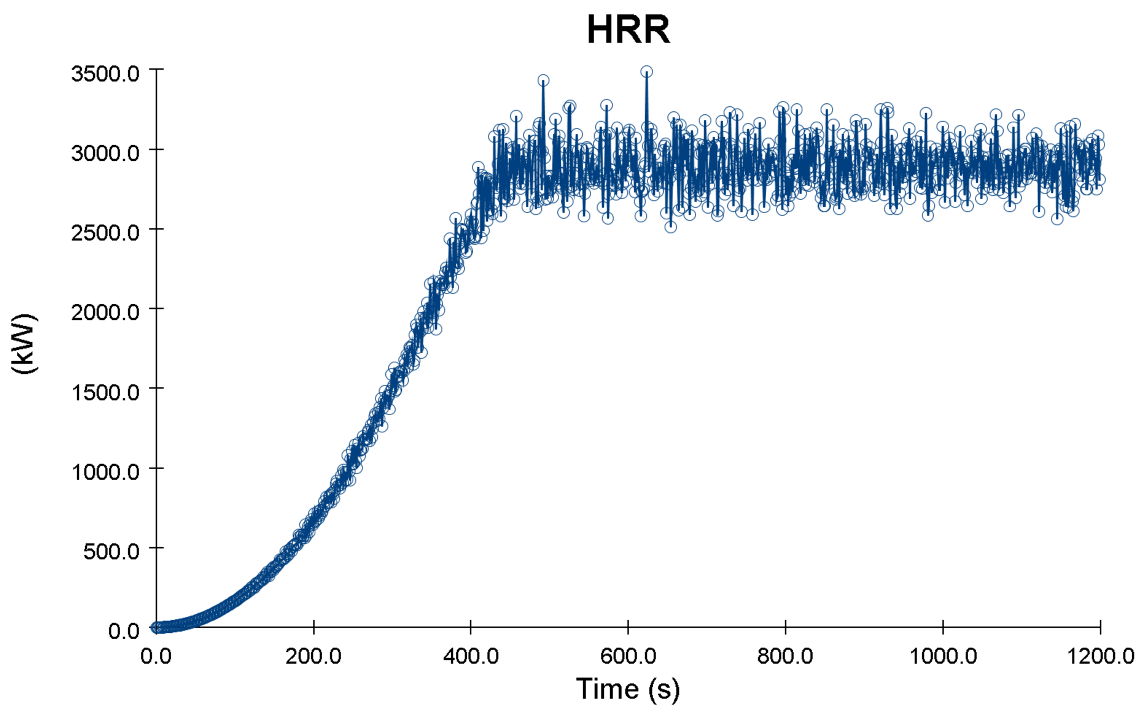
4.5.1 Flame Height

With reference to Figure 46, the height of the flame sustained in Model 1 consisted of a full height flame, at the 750 second mark the flame entered the cavity and reached the top of the rig (i.e. 6.8 m) from the floor of the Fire Room., this is due to a combination of the chimney effect as well as the small width the cavity. It is noted that the performance criteria set out in SP Fire 105, requires the maximum height above the first window not to exceed 4.2 m above the first window opening, with the model simulation it was observed that the flame height exceeded the maximum height criteria, as such fails the SP Fire 105 test criteria.

Figure 46 – Snapshot from the modelling 3 showing height of the flame

4.5.2 Heat Release Rate

The maximum heat release rate of approximately 3000 KW was reached after 400 s of run time, the HRR reached in the SP Fire 105 test used for validation was 2500 KW, although this is lower than the results generated, it is somewhat consistent considering the different variables that have taken place due to the modelling.



Graph 16 – Graph showing heat release rate of the fire of Model 3

4.5.3 Temperature

With reference to Figure 47 , the maximum temperature reached was 820ºC and stayed constant throughout the duration of the simulation, this is because the façade did not burn away nor did it contribute to the fire load as it was non-combustible. The below thermographic shows that the heat within the cavity reached between 500 – 600ºC, with comparison the Model 3 where the cavity barriers were installed, the thermographic showed that the heat did not enter the cavity to a significant degree.

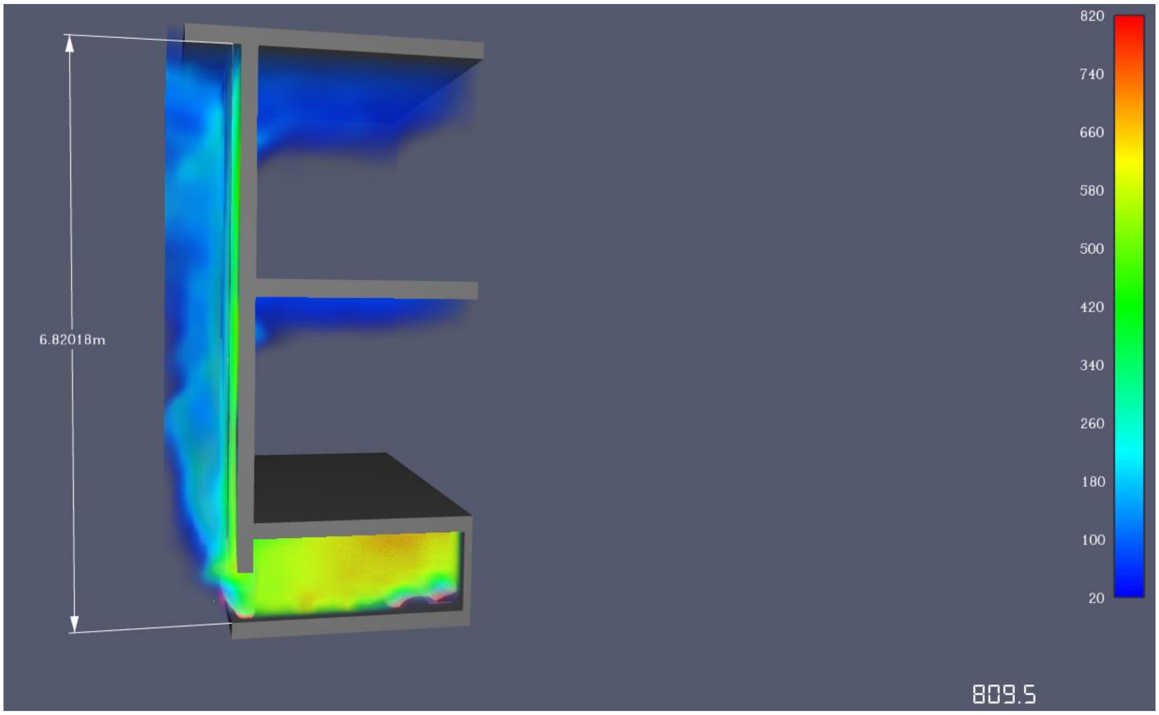
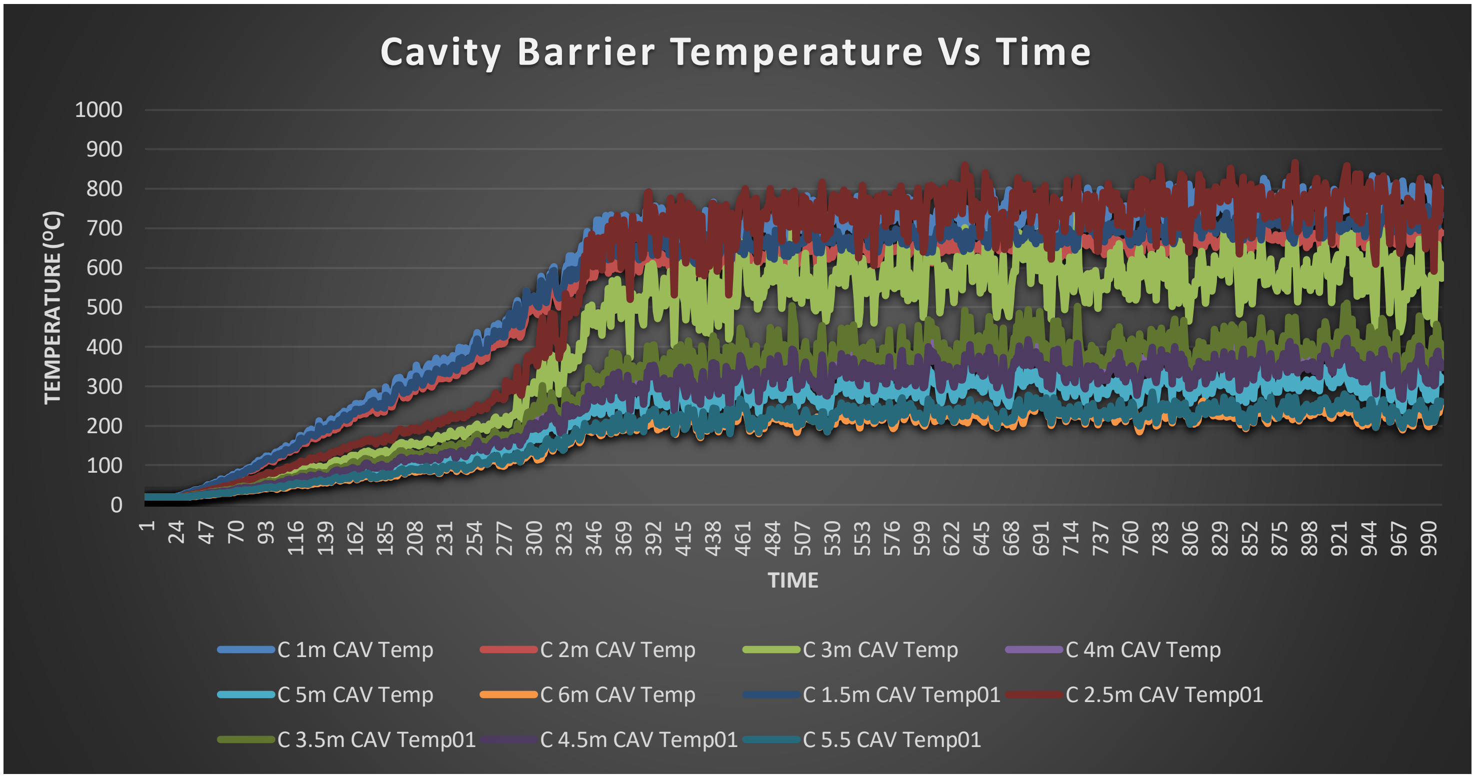


Figure 47 – Snapshot of Model 3 thermographic showing maximum temperature reached

The temperature within the cavity reached a maximum of approximately 833°C at a height of 1m and 709°C at 2m , this is as a result of there being no cavity barriers installed to block the fire from entering the cavity, with comparison to Model 3 where the maximum temperature of the cavity at 1m was 567°C and 262°C at 2m. It is to be noted that the cavity barrier was installed above the 1m mark, and as such it wasn't expected that the temperature would be reduced. However, the difference of 447°C on Level 2 is a direct result of the impact of the cavity barrier blocking the flame and radiant heat from passing through the cavity. The cavity temperature plotted on the below graph shows that the cavity temperature at the higher areas was lower than the temperature at the lower area. This is because there was no burning fuel load and the flame height of the temperature stayed relatively constant throughout the simulation.



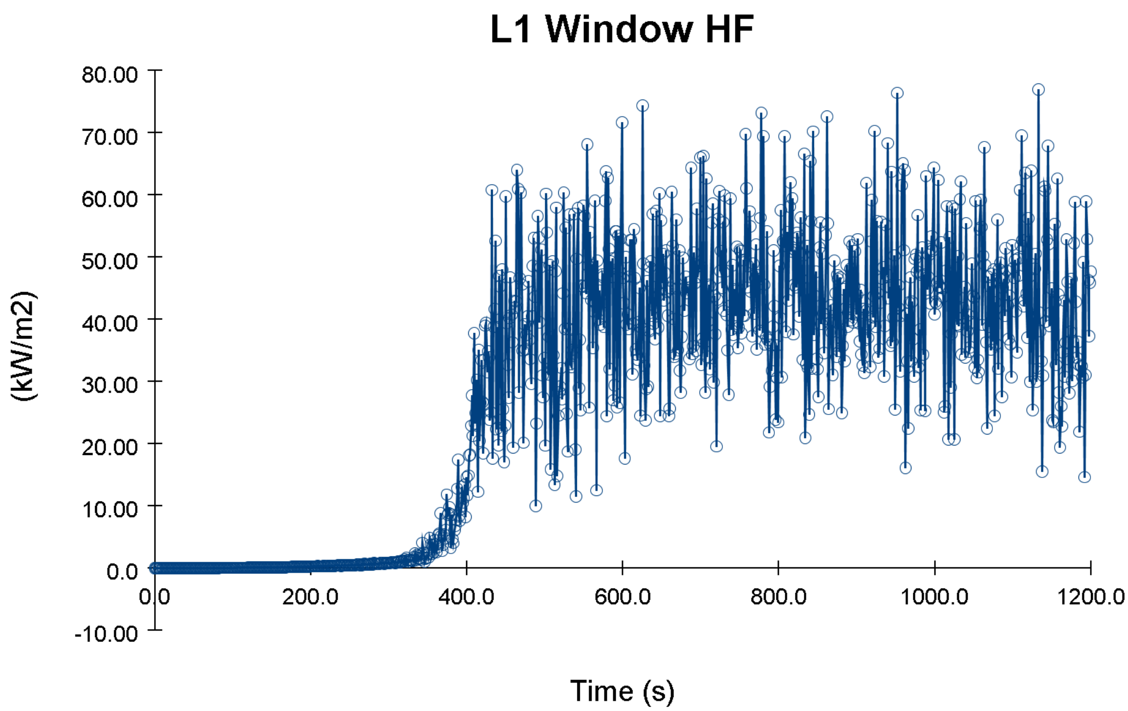
Graph 17 – Graph showing temperature of the cavity at different heights of Model 4

Table 12 – Maximum temperatures at the eaves and 1 m intervals within the cavity

Eave	Cavity 1m	Cavity 2m	Cavity 3m	Cavity 4m	Cavity 5m	Cavity 6m
Maximum Temperatures						
348°C	833°C	709°C	746°C	448°C	361°C	269°C

4.5.4 Heat Flux

With reference to Graph 18, the heat flux achieved at the window of level 1 within the cavity was a maximum of 80 kW/m^2. The heat flux at the first window stayed relatively constant from 500 to 1200 seconds between 50 – 80 kW/m^{2+}. The fluctuations shown in the below graph are a result of the flame flickering.



Graph 18 – Heat flux at the window of Level 1 against time of fire

5 CHAPTER V: FINDINGS AND DISCUSSION

In this paper we explored the effects cavity barriers have on external fire spread on a multistorey building. The model was based on the Swedish large-scale façade fire test established in 1985, known as the SP Fire 105. There were five (5) models simulated, the first being a replica of the SP Fire 105 test as to verify the simulation against real life and other simulated models conducted across the board. The other four (4) models consisted of the variant models to assess the effects of cavity barriers, which were as follows:

- Model 1 comprised combustible cladding with cavity barriers on the slab edge of Level 1 and Level 2;
- Model 2 comprised combustible cladding without cavity barriers;
- Model 3 comprised non-combustible cladding with cavity barrier on the slab edge of Level 1 and Level 2; and
- Model 4 comprised non-combustible cladding without cavity barriers.

As such the two (2) variables with all the models conducted being the installation of cavity barrier and the façade cladding attachment. It is to be noted that the base model as per the SP Fire 105 test comprised of fictitious windows which were not open and just a 50 mm indent in the concrete external wall, whereas the four (4) variant models comprised of a window opening that was actually open, this was done to simulate a more realistic residential building façade, where windows are usually located.

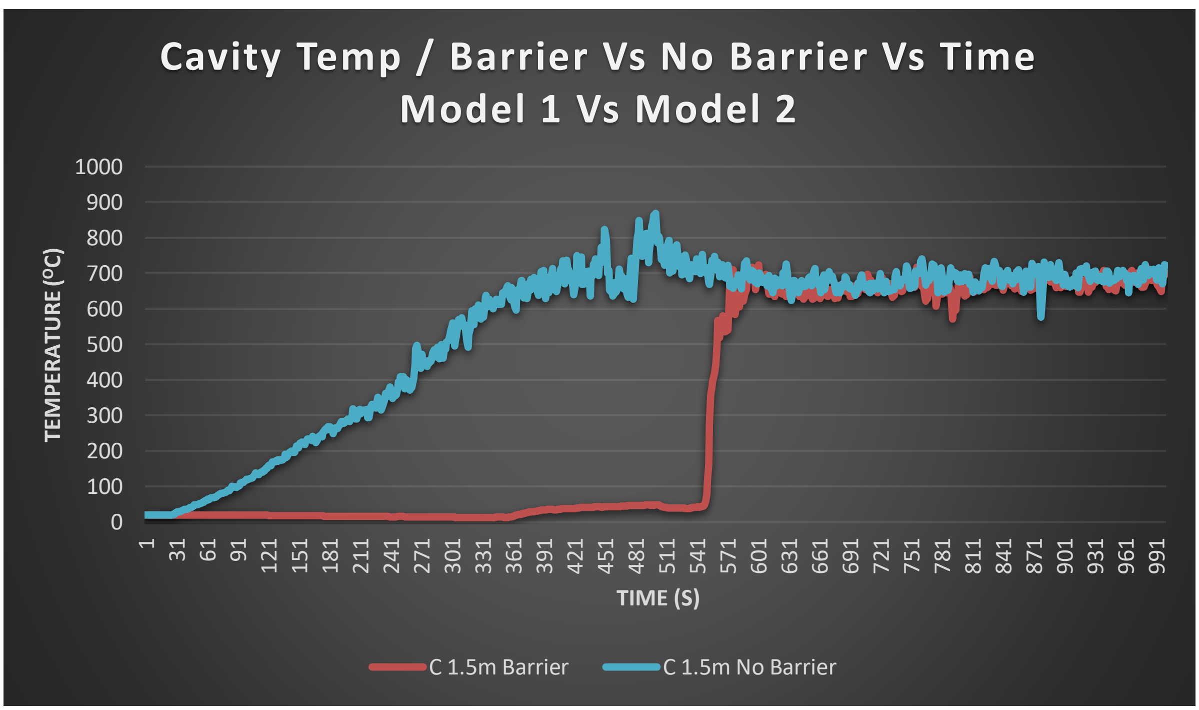
The models were assessed against the Performance Criteria set out in the SP Fire 105 test, as per the below table:

Table 13 – SP Fire 105 Performance Criteria

Performance Criteria	
External Fire Spread	No fire spread >4.2 m above opening (bottom of fictitious window) Temps at the eave must not exceed 500°C for more than 2 min or 450°C for more than 10 min for buildings > 8 stories high or hospitals, heat flux <80 kW/m^2, 2.1 m above opening
Internal Fire Spread	No fire spread > 4.2 m above opening (bottom of second storey fictitious window)
Burning Debris	To be reported but criteria not specified by standard
Mechanical Behavior	No large pieces are permitted to fall from the building

Based on the results observed in the base model, the criteria shown above is met, this is because this model comprised of a solid concrete wall as the façade with no cavity, hence the flame height and external temperature and heat fluxes is directly correlated to the size of the fire which was set at 2MW from the 60 Litre Heptane tray located in the Fire Room. The temperature at the eave stayed below 360°C which is less than the 450°C requirement, the heat flux of Level 1 window stayed below 35kW/m^2 which is less than the 80kW/m^2 requirement.

Model 1 and 2 consisted of 100% Polyethylene cladding core with and without cavity barriers, the results for these two models were relatively consistent as the cladding caught after about 600 seconds of simulation. After which, the size of the fire increased from 3MW up to 10MW until the cladding started to burn away, which caused the size to drop back down to ~2.5MW. It is to be noted that the cavity barriers in this instance did not mitigate fire spread up the building as the cavity was exposed once the cladding burnt away. With reference to the below graph it can be observed that at the 1.5 m mark the temperature of the cavity before the cladding started to burn away was significantly different between the model with cavity barriers installed and the model with no barriers, the red line shows the temperature staying below 50°C for a duration of 560 seconds, after which the cladding started to burn away and the temperature spiked to a maximum of 723°C whereas the blue line shows the temperature gradually increasing from 0 to 868°C at 500 seconds. The model showed that the application of cavity barriers mitigate the fire from entering the cavity at the early stages of the fire and retained the cavity temperature low, however as soon as the cladding caught alight the temperature increased to exponentially to the same temperature as the model with no cavity barriers, as such in this case cavity barriers will not be effective as the cladding propagates fire spread significantly regardless of cavity barrier installation.



Graph 19 – Cavity temp at 1.5 m shown for model 3 & 4 (barrier Vs no barrier - combustible)

Model 3 and 4 comprised of non-combustible cladding with and without cavity barriers installed along the slab edge of Level 1 and 2. The results in these models showed the most significant changes, and proved that the installation of cavity barriers in very effective in reducing fire spread within the cavity. It showed that the flame height did not increase as there was no fuel load to contribute to fire propagation as the façade was non-combustible. Furthermore, the cavity barriers mitigated fire entry into the cavity, where's the model without any cavity barriers, the flame reached the top of the rig as fire entered the cavity and due to the chimney effect spread up the building relatively quick.

With reference to the below figure, the model on the left (Model 3) consisting of cavity barriers shows that the gases in the cavity are relatively ambient as opposed to the model on the right (Model 4) which shows a temperature of around 500-600^{o}C as indicated by the greenish/yellowish thermographic outlines of the gaseous entries.

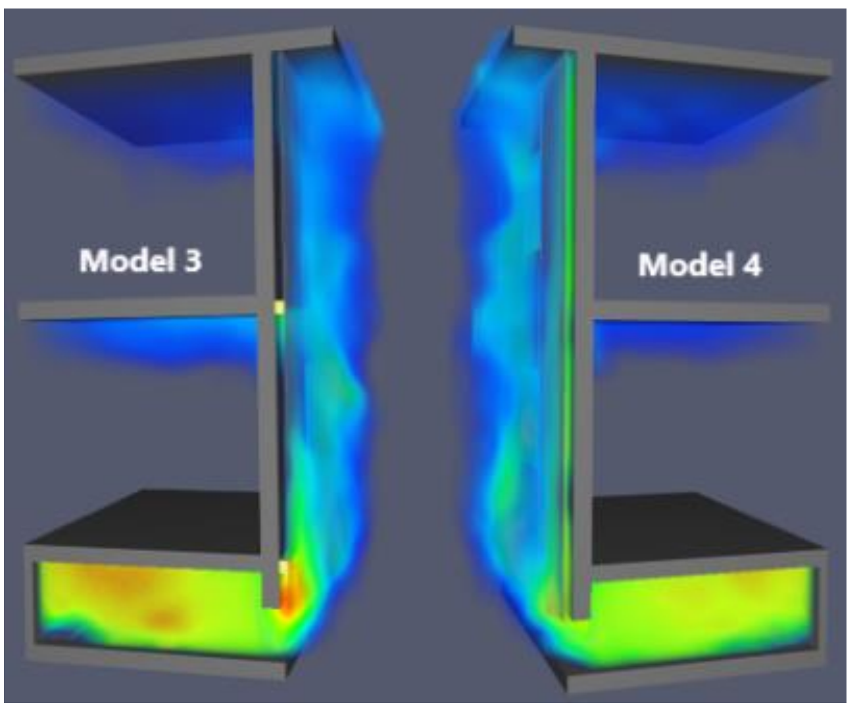
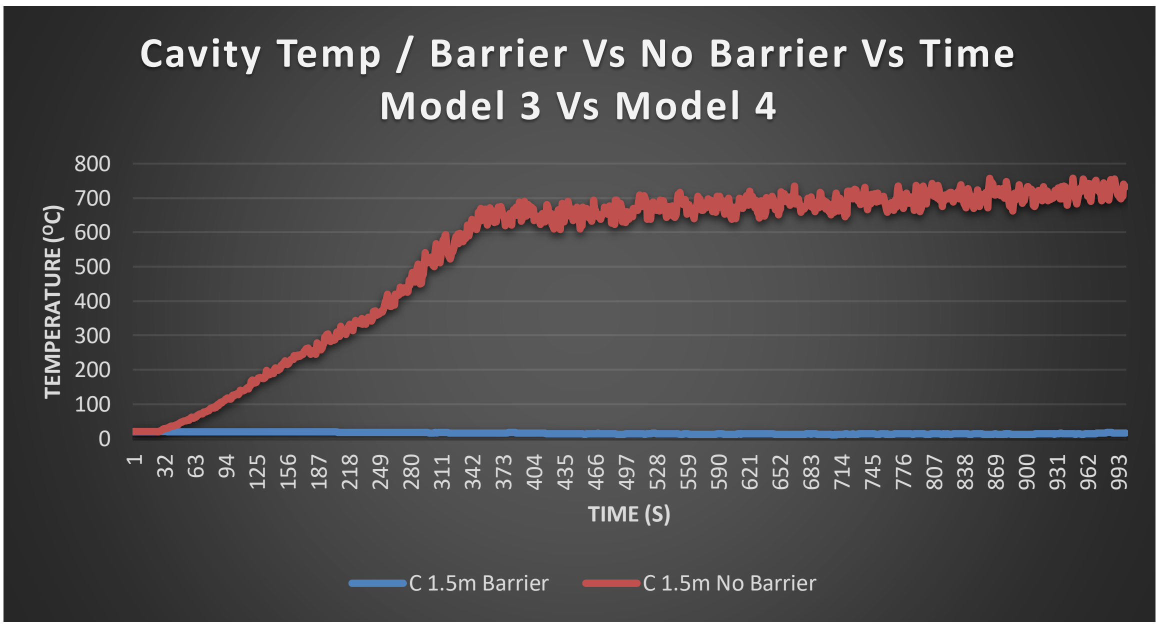


Figure 48 – Thermographic comparison between Model 3 & 4 showing cavity temperature

With reference to Graph 20, it can be observed that the cavity temp at a height of 1.5 m is significantly different between Model 3 and Model 4, this shows how effective installing cavity barriers are on a building with non-combustible cladding as a façade attachment. The temperature as shown by the red line for the model with no cavity barriers sustained a maximum temperature of 757^{o}C at around 990 seconds while the maximum temperature sustained for the model with cavity barriers was only 20^{o}C, it is noted that these temperatures were taken directly above the placement of the Level 1 cavity barrier.



Graph 20 – Cavity temp at 1.5 m shown for model 3 & 4 (barrier Vs no barrier, non-combustible)

As per the above findings, it is evident that the installation of cavity barriers on buildings with no combustible and low combustible content cladding, would have a significant positive effect on the mitigation of external fire spread.

Upon reviewing the results of the modelling conducted it was discovered that the models with combustible cladding, the size of the fire for Model 1 (i.e cavity barriers installed) grew slightly larger (i.e. 10MW) than the model with no cavity barriers (i.e. 7MW) this is also evident in the simulation run time as the cladding started to burn away approximately 50 seconds earlier. Upon investigation of this phenomenon it was assumed that the result of the increased fire size was due to the fire being more concentrated at the lower levels due to the fire blockage caused by the cavity barrier. The blockage caused the fire to become more concentrated at the lower levels and in turn became slightly larger in size which caused the cladding to start burning quicker as opposed to the model without the cavity barrier.

It is to be noted that these findings are based on the models simulated and do not represent the results of real-life large-scale fire tests.

It can be seen in the below figure that the cladding on Model 1 started to burn before the cladding on Model 2 at the same time stamp of 450.6 seconds.

Figure 49 – different between cladding fire on Model 1 and 2 at 450 seconds

6 CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

The hypothesis presented in this report based on the research conducted of previous research papers, suggested that the use of cavity barriers will mitigate fire spread on a building, regardless of façade attachments.

The findings in this research paper are to the most part consistent with the hypothesis presented in the literature review, in that the installation of cavity barriers is effective in mitigating external fire spread. This is done by limiting the fire to spread through the cavity and keeping the temperature within the cavity below 250^{o}C. However, it was discovered when extrapolating the results of the models simulated with combustible cladding that the cavity barriers contributed to the speed at which the cladding ignited, as the fire size was increased as a result of the fire being blocked by the cavity barriers, which in turn caused the cladding on the lower portion of the test rig to ignite as the flame heated up quicker.

The cavity barriers installed on the non-combustible façade showed a significant improvement over the model that did not comprise cavity barriers and based on the modelling shows that the cavity barriers completely blocked the fire from entering into the cavity and in turn stopped the vertical spread of fire.

In the future it would be recommended that a model with a cladding attachment that has a core of 30% combustible content is conducted with and without cavity barriers. This is because most cladding products on buildings in NSW contain a combustible content of between 25 – 30%. This will be important to conduct as the results of the BRE tests discussed in Section 2.6 above, shows that the cladding with 30% combustible content was very similar to a non-combustible cladding, as in it did not propagate fire spread but rather just melted at the point of direct flame impingement from the size of the fire.

The implications associated with computer modelling is the accuracy of the results presented, as there are many variables such as wind, concrete reaction and façade attachment that have not been taken into consideration. Furthermore, with regard to FDS simulation the finer the mesh the more accurate the results, however due to time constraints and computer capabilities available for this research, a relatively course mesh was used. It is to be noted that the mesh used in this research was calculated to be enough for the intent of the report.

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Appendix A – NSW Product Ban

BUILDING PRODUCT USE BAN

NOTICE UNDER SECTION 9(1) OF THE *BUILDING PRODUCTS (SAFETY) ACT 2017*

I, Rosemary Ann Webb, Commissioner for Fair Trading, Department of Finance, Services and Innovation:

PROHIBIT the use of aluminium composite panels (ACP) with a core comprised of greater than 30 per cent polyethylene (PE) by mass ('the building product') in any external cladding, external wall, external insulation, façade or rendered finish in:

- Class 2, 3 and 9 buildings with a rise in storeys of three or more and Class 5, 6, 7 and 8 buildings with a rise in storeys of four or more (Type A construction as defined in the Building Code of Australia); and
- Class 2, 3 and 9 buildings with a rise in storeys of two or more and Class 5, 6, 7 and 8 buildings with a rise in storeys of three or more (Type B construction as defined in the Building Code of Australia),

subject to the following exceptions:

a) the building product is not deemed combustible by successfully passing a test in accordance with Australian Standard 1530.1-1994 'Methods for fire tests on building materials, components and structures' (AS 1530.1);

or

b) the building product and proposed external wall assembly has successfully passed a test for both the EW (external wall fire spread) and BB (building-to-building fire spread) classifications in accordance with Australian Standard 5113 'Fire Propagation testing and classification of external walls of buildings' (AS 5113) and the proponent of the use of the building product tested to AS 5113 documents by statutory declaration that the building product will be installed in a manner identical to the tested prototype wall assembly or façade,

and

c) the AS 1530.1 or AS 5113 test results to be relied upon to except a building product from the ban are produced by an Accredited Testing Laboratory, and describe the methods and conditions of the test and the form of construction of the tested building product or prototype wall assembly or façade, and are dated on or after 1 July 2017.

This building product use ban commences Wednesday 15 August 2018 and remains in force until it is revoked.

DATED the 10th day of August 2018.

ROSEMARY ANN WEBB
COMMISSIONER FOR FAIR TRADING
DEPARTMENT OF FINANCE, SERVICES AND INNOVATION

Notations

For the purposes of this Notice:

Accredited Testing Laboratory means:

i. an organisation accredited by the National Association of Testing Authorities (NATA) to undertake the relevant tests; or

ii. an organisation outside Australia accredited to undertake the relevant tests by an authority, recognised by NATA through a mutual recognition agreement; or

iii. an organisation recognised as being an *Accredited Testing Laboratory* under legislation at the time the test was undertaken.

Proponent is taken to be one of the following persons:

i. the person recommending or specifying the use of the building product;

ii. the person who uses the building product; or

iii. the Owner within the meaning of the *Building Products (Safety) Act 2017* ('the Act').

Rise in storeys has the meaning given to it in Clause C1.2 of the BCA.

Under the Act, it is an offence for a person to cause a building product to be used in a building in contravention of a building product use ban.[1]

It is also an offence under the Act for a person to, in trade or commerce, represent that a building product is suitable for use in a building if that use would contravene a building product use ban.[2]

Part 4 of the Act makes provision for the identification and rectification of buildings where a building product the subject of a building product use ban has been used in the building for a use that is prohibited by the building product use ban. For the purposes of that Part of the Act, it does not matter if the building product was used in the building before the building product use ban is in force.[3]

Reasons for Decision

On 23 March 2018, I published a Notice under section 13 of the Act (the Notice) calling for submissions by 23 April 2018 on whether a building product use ban was warranted for the use of ACPs, particularly panels containing a polyethylene core, and/or polystyrene products, and/or other similar substances in any external cladding, external wall, external insulation, façade or rendered finish on a building of 2 or more storeys (use in external cladding).

I received 28 public submissions in response to the Notice. The submissions were provided by a range of stakeholders including developers, builders, industry associations, fire safety consultants, composite panel suppliers and individuals.

In deciding whether to impose a building product use ban, I have had regard to all public submissions that were received in response to the Notice.

I have also considered:

(a) advice from NSW Fire and Rescue;
(b) independent expert advice specifically sought by the Department of Finance, Services and Innovation from building safety professionals with relevant technical knowledge and professional expertise;
(c) the post incident analysis report of the Lacrosse Building fire by The Metropolitan Fire and Emergency Services Board dated 25 November 2014;
(d) the Economic References Committee, *Non-conforming building products – Interim report: Aluminium composite cladding* dated 6 September 2017;
(e) the *Australian Government response to the Interim report: Aluminium Composite Cladding* dated 26 February 2018;
(f) the Phase 1 expert report of Professor Luke Bisby dated 2 April 2018 submitted to the Grenfell Tower Inquiry;
(g) the approaches which have been adopted by other Australian Regulators, namely Victoria, Tasmania and South Australia on the use of certain types of composite panelling; and
(h) publications of the NSW Cladding Taskforce.

In reaching a decision, I have had regard to:

- the likely contribution of specific types of ACPs to building fire safety
- whether certain types of ACPs are unsafe within the meaning of the Act and should be banned from use in certain classes of building, and
- whether any compliance tests exist to sufficiently manage the safety risks posed by certain products.

Having considered all of this information, I am satisfied that the building product is unsafe for use in any external cladding, external wall, external insulation, façade or rendered finish in buildings of Type A and Type B construction, as defined in the Building Code of Australia, subject to specified exceptions. I therefore decided to prohibit the use of the building product in the terms of the building product use ban set out above. My reasons for making this decision are as follows:

<u>1) Fires which are associated with ACP with a PE core on Type A and Type B construction pose a safety risk</u>

Recent public events have demonstrated the safety risk associated with the use of ACP with a PE core in multi storey buildings, including Type A and Type B construction. Events such as the Lacrosse building fire in Melbourne on 25 November 2014 and the Grenfell Tower fire in London on 14 June 2017 demonstrated that there are likely to be public safety risks associated with the use of certain types of cladding, including ACP with a PE core. Similar fire events in China, France and the United Arab Emirates have also been linked to the use of combustible cladding.

Fires on multi storey buildings have a range of inherent complexities resulting from the height of the building and may require more specialised equipment. Fires which are associated with external cladding consisting of ACP with a PE core, such as the Lacrosse Building fire and the Grenfell Tower fire, introduce additional risk owing to the rapid vertical spread of fire associated with these building products. Such fires must be carefully managed to respond to the potentially higher incidence of fatalities which are more likely to be caused by such a fire.

The Lacrosse Building fire was managed by an internal sprinkler system that was found to have operated well above specification in the majority of the units impacted by the fire to stop its spread. It therefore cannot be presumed that a sprinkler system would operate to mitigate the spread of fire in similar circumstances.

NSW Fire and Rescue identify building products including ACP with a PE core as a safety risk capable of causing rapid fire spread. The use of such building products may put fire fighters and occupants in unsafe situations including exposure to falling debris in the instance of fire.

2) ACP with a core comprised of greater than 30 per cent PE by mass used in contravention of the National Construction Code (NCC) poses a safety risk within the meaning of the Act

The various types of ACP are distinguished by the composition of their core. The composition of the core is important as it is considered to significantly influence the fire properties of the panel. The majority of ACPs have a core material that is a mixture of PE, mineral fillers and/or fire retardants. The CSIRO, who were asked to provide advice by the Australian Government on the various types of ACPs currently manufactured, described three 'classes' of core composition:

1) Less than three per cent PE – such composition produces a product classified as 'A2' ACP under European fire certification;
2) Approximately 30 per cent PE – such composition produces a product classified as 'FR' (fire retardant) under European fire certification; and
3) Approximately 100 per cent PE.

Unlike European fire certification, the NCC does not consider or make distinctions based on the composition of panels, including the core, as it requires ACP to be non-combustible as defined by AS 1530.1. However, some Australian suppliers identify their ACP products as complying with A2 or FR European standards to represent that the ACP product is non-combustible.

PE is a thermoplastic substance which has poor fire performance and is quickly prone to melting and dripping when exposed to high temperatures, such as in the event of a fire. The heat from a fire can quickly conduct through the outer ACP, noting the width of these panels is no greater than 6mm, and ignite the highly flammable core. These materials combust in a manner that makes fire response extremely challenging for emergency services.

Cladding, including ACP with a PE core of some proportion, is often used for the purposes of aesthetics to act as a cover for part or all of the external walls of a building. In the event of a fire, the use of ACP with a PE core on a multi storey building can significantly increase the amount of energy that is released by the cladding and contribute to the rapid spread of fire.

A ban directed only to ACP with a core comprised of greater than 30 per cent PE targets the impact of the product ban and focuses regulatory intervention on the types of ACP panels that are most likely to pose a safety risk. This threshold aligns with the FR European standard which is considered the benchmark for an ACP product to be of low flammability.

Given that the Victorian Building Authority also enforces a restriction on ACP with a core specifically comprised of 30 per cent or more PE by mass, it is considered appropriate to align NSW's building product use ban with the requirements of the second largest state in which construction work is performed. It is noted however that the Victorian approach differs from the NSW approach. Under the Victorian approach products are required to be submitted to the Victorian Building Appeals Board to be determined whether the proposed use of the product complies with the relevant Act and Regulations. In this regard, the Victorian approach equates to an 'approval' under the Victorian planning and building regime. The NSW approach under the proposed ban creates a specific gateway which affected products must navigate, but still requires that the product and the related construction use is separately and additionally subject to all the normal planning assessment and approvals, including compliance with the NCC, under NSW laws.

3) At present, the NCC is not sufficient to regulate building products and cannot be relied on in isolation to address the safety risks associated with the use of ACP with a core comprised of greater than 30 per cent PE by mass

The NCC is a national performance-based code which outlines mandatory performance requirements for the building and construction industry. Under the NCC, ACP with a PE core is permitted for use if the product satisfies the performance requirements of the NCC.

However, misapplication of or non-compliance with the performance requirements of the NCC raises a significant risk and concern for the safety of buildings and the community.

The operation of the NCC presents challenges to entities in the building industry and regulators. Concerns with the combustibility of external cladding (specifically ACP with a PE core) and the role of the NCC have been noted in reports by domestic and international bodies. There is evidence that NSW is directly affected as the NSW Cladding Taskforce identified over 400 buildings as "having cladding in a quantity, location and/or arrangement which potentially increases fire risks" despite the requirements of the NCC.

Victoria, South Australia and Tasmania have determined it appropriate to implement new measures in addition to existing requirements under the NCC to respond to the challenge of non-compliant cladding.

Based on the sources considered, a genuine concern exists that the NCC cannot be relied on in isolation to address the safety risks associated with the use of ACP with a core comprised of greater than 30 per cent PE by mass.

<u>4) A building product use ban can be imposed subject to exceptions that will enable the use of the building product if a nominated test is satisfied</u>

Expert advice and other sources which I considered identified recognised testing that applies to the building product as determined by Australian Standards and/or in certain circumstances called upon by the NCC, including AS 1530.1 and/or AS 5113. I have formed the view that the safety risk posed by ACP with a core comprised of greater than 30 per cent PE by mass can be managed if the product meets the testing requirements of AS 1530.1 and/or AS 5113. For this reason, the building product use ban is subject to exceptions that permit the use of the building product in Type A and Type B construction if the building product is tested in accordance with either AS 1530.1 or AS 5113.

AS 1530.1 is an individual product test which determines the combustibility of a building material within the criteria given in Clause 3.4 of the Standard. Separately AS 5113 sets out the procedures for the fire propagation testing and classification of external walls of buildings according to their tendency to limit the spread of fire via the external wall and between adjacent buildings. AS 5113 is more appropriate for testing entire wall assemblies or façades consisting of external cladding, rather than an individual product. This Standard is applicable to fire propagation via all external vertical or near vertical surfaces and covers all types of external wall systems, including façades, outer skins, core materials, cavities and attachments. The application of AS 5113 as part of a building product use ban is considered appropriate to ensure that building products that pose a safety risk, including to the lives of occupants, fire fighters and the community, are not used in NSW.

In order to meet the requirements of the proposed exception it is considered appropriate that tests be supported with a report from an Accredited Testing Laboratory which describes the methods and conditions of the test, the form of construction of the tested prototype. Where AS 5113 is relied upon, a statutory declaration will be required by the proponent of the use of the building product to declare that the building product will be installed in a manner identical to the tested prototype wall assembly or façade. This additional step is required to ensure that proponents understand and verify that the prototype wall assembly tested is in fact the wall assembly subsequently used and installed.

To ensure that testing takes account of the understanding of the fire performance of ACP products since the Grenfell Tower Fire, test reports against AS 1530.1 and/or AS 5113 are required to have been undertaken no earlier than 1 July 2017.

Appendix B – Cladding Material Database

ACP 03 – PE ACP Information

Material description

Material ID: ACP03

Material type: Aluminium composite panel with a core consisting of polyethylene (PE).

Polymer: Polyethylene (99%)

Additives (fire retardants, fillers or traces of inorganic elements): Calcium (1%), traces of other elements (<1%)

Core thickness: 2.86mm

Thickness of single metal skin: 0.5mm

Table 1. Estimated mass concentration of compounds.

Compound	Mass Concentration (%)
Polyethylene (PE)	99
Calcium (Ca)	1
Traces of iron (Fe)	<1
Traces of potassium (K)	<1
Traces of phosphorus (P)	<1
Traces of aluminium (Al)	<1
Traces of silicon (Si)	<1

B. Thermogravimetric analysis

Table 3. Mass fraction of residue after thermal decomposition.

Condition	Fraction of mass residue at 800°C
Non-oxidative (nitrogen)	0
Oxidative (air)	0

Table 4. Temperature and amplitude of main peaks in non-oxidative conditions.

Peak ID	Temperature peak (°C)	Amplitude of peak (°C^{-1})
Peak 1	483	3.237×10^{-2}

Table 5. Temperature and amplitude of main peaks in oxidative conditions.

Peak ID	Temperature peak (°C)	Amplitude of peak (°C^{-1})
Peak 1	385	9.59×10^{-3}
Peak 2	442	1.031×10^{-2}
Peak 3	547	1.03×10^{-3}

C. Gross Heat of Combustion

Table 7. Gross Heat of Combustion individual results for sample.

Trial	ΔH_c [kJ g^{-1}]
Trial 1	46.63
Trial 2	46.53
Trial 3	46.71
Average	46.62
Std dev	0.09

D. Ignition parameters

Table 8. Summary of ignition parameters for sample.

Critical heat flux for ignition	Ignition temperature	Total heat transfer coefficient of losses	Apparent thermal inertia
q''_{cr} [kW m^{-2}]	T_{ig} [°C]	h_r [W m^{-2} K^{-1}]	$k\rho c$ [kW^2 m^{-4} K^{-2} s]
17.20	398	41	0.632

E. Burning behaviour

Table 9. Summary of key burning behaviour metrics.

Heat flux	Test	Time to ignition	Fraction of mass residue	Peak heat release rate	Total energy released
q''_{inc} [kW m^{-2}]		t_{ig} [s]	m_{res} [-]	q''_p [kW m^{-2}]	Q_t [MJ m^{-2}]
35 kW m^{-2}	Test 1	71	0.13	641.65	90.88
	Test 2	72	0.12	637.78	95.25
	Avg	72	0.13	639.72	93.07
50 kW m^{-2}	Test 1	39	0.15	944.79	98.47
	Test 2	23	0.15	504.52	88.13
	Avg	31	0.15	724.65	93.30
60 kW m^{-2}	Test 1	27	0.12	1198.29	92.61
	Test 2	26	0.14	874.65	82.92
	Avg	26	0.13	1036.47	87.76
80 kW m^{-2}	Test 1	-	-	-	-
	Test 2	-	-	-	-
	Avg	-	-	-	-

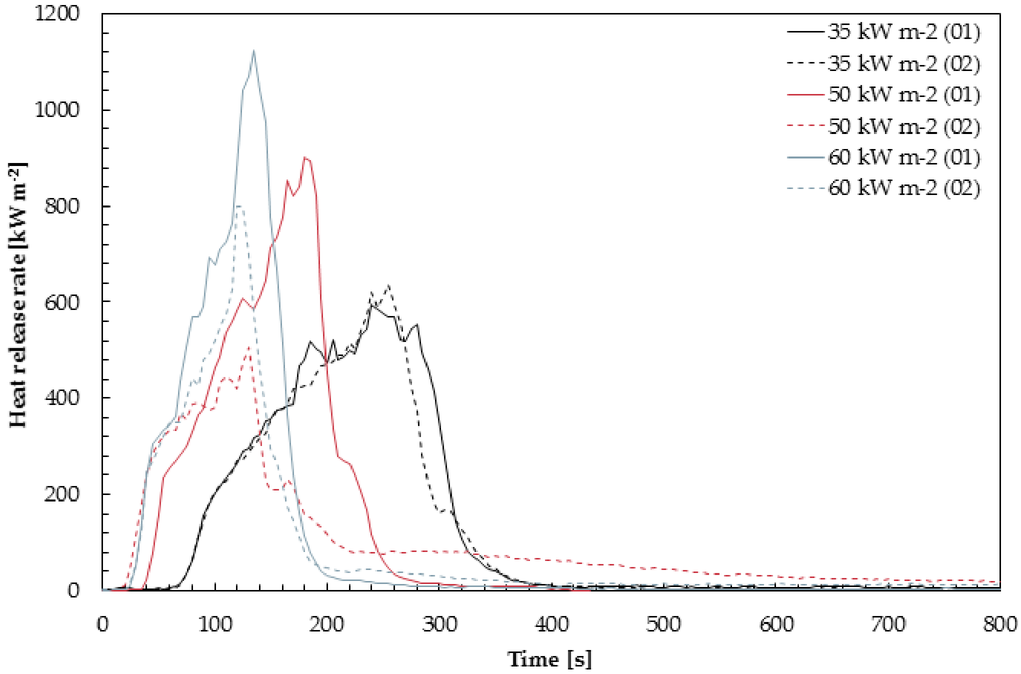

Figure 8. Heat release rate per unit area over time for samples tested with 35, 50, 60 and 80 kW m^{-2}.

Appendix C – Thermal Properties Table

The following table was used in this research paper to determine thermal properties of certain building elements – this was taken from the following website:

http://thermalanalysislabs.com/thermal-properties-of-common-materials/

Material Name	Density	Specfic Heat	Thermal Conductivity	Thermal Effusivity
	kg/m^3	J/kgK	W/mK	$Ws^{.5}/m^2K$
Air	1.29	1004	0.025	6
Aluminum	2698	921	226	23688
Bronze, silicon, high	8530	377	33	10369
Carbon, graphite (typical k)	2250	707	167	16318
Concrete, lightweight	950	657	0.209	361
Copper	8940	385	397	36983
Epoxy, unfilled, cast	1200	1046	0.188	486
Fireclay brick, missouri	2000	753	1.004	1230
Fused silica glass	2200	745	1.381	1504
Gold	19300	128	318	28027
Limestone (h2o 15.3)	1650	921	0.92	1182
Magnesium	1740	1004	151	16221
Mica insulating powder	330	837	0.121	183

Material Name	Density	Specfic Heat	Thermal Conductivity	Thermal Effusivity
	kg/m3	J/kgK	W/mK	Ws.5/m2K
Polymethyl methacrylate	1180	1464	0.209	601
Polystyrene, foamed-in-place, rigid	**100**	**1130**	**0.035**	**63**
Polyvinyl butyral	1100	1674	0.084	393
Polyvinylidene chloride	1700	1339	0.126	535
Pyroceram 9608 ceramic glass	2500	808	2.05	2034
Rubber, butyl	900	1966	0.088	394
Rubber, natural	930	2092	0.138	518
Rubber, natural, foam	100	2092	0.042	94
Silver	10500	236	427	32520
Soil, sandy dry	1650	795	0.264	588
Steel, stainless 304	7920	502	15	7631
Steel, stainless 446	7600	460	23	8955
Steel, stainless 501 and 502	7800	460	38	11626
Teflon	2170	1004	0.251	740
Water (liquid)	1000	4184	0.603	1588
Window glass, lime	2480	753	1.318	1569

Appendix D – Supervisors Certification Form

School of Built Environment

301056 Research Project B

Supervisor's Certification Form for the Final Submission

Important note related to final submission:

- Please submit this form attached to the final report on VUWS.
- Please note if this form is not submitted, the final report will NOT proceed to the examination stage.
- Please make sure to attach a signed and dated 'Statement of Authentication' within your final report.
- Also, please make sure that you submit supporting data files to your supervisor. In the event of any examination issues, these will be requested from your supervisor for verification.

Your name: Yahya Elhallak

Thesis Title:

The Use of Cavity Barriers to Mitigate External Fire Spread in Multi-Storey Buildings

Your signature: Y.Elhallak

Date: 31/10/2020

Certification of the (Principal) Supervisor

As the principal supervisor for the above student, I certify/do not certify that the accompanying thesis is in a form suitable for examination.

Supervisor's signature:

Date: