CladFire Project:
Results and Analysis

Cameron MacLeod[a], Neal Butterworth[b], Angus Law[a]

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[a] Edinburgh Fire Research Centre
School of Engineering
The University of Edinburgh
Scotland

[b] Design Fire Consultants Ltd.
Leeds
United Kingdom

Overview

The Grenfell Tower fire resulted in 72 deaths, and precipitated a building safety crisis within the United Kingdom. For many buildings, remedial works were deemed as being required to achieve an adequate level of safety. However, identifying which buildings should be remediated – and to what extent – is a highly subjective process.

To provide a framework for such assessments, government sponsored the creation of a Publicly Available Standard (PAS 9980 [1]). PAS 9980 sets out a process whereby the fire risk associated with external cladding systems can be assessed. There are three key parts of the analysis:

1) Fire performance risk factors. These relate to the materials and products used in the external wall system and their configuration in relation to one-another.
2) Façade configuration risk factors. These relate to factors such as the extent of cladding systems, and the locations of openings into the building.
3) Fire strategy risk factors. These relate to wider building considerations such as the presence or extent of detection and the locations of escape routes.

For many engineers, assessing items 2) and 3) is a relatively straightforward exercise. This is because information relating to fire strategy, and the location and extent of combustible cladding ought to be readily available – or can be obtained through investigation. However, assessing item 1) is more challenging as the assessor requires detailed knowledge of the cladding materials and products and how they may (as an assembly) react in a fire.

Assessors may obtain such information from a variety of sources such as reaction-to-fire testing or large-scale fire tests (e.g. BS 8414 [2] [3]). However, such supporting information may not be readily available for existing buildings, or may be prohibitively expensive and/or time-consuming to generate.

The Grenfell Tower Inquiry Phase 2 report [4] highlighted the need for practitioners to have access to a body of information – "such as data from tests on product and materials". The Inquiry recommended that the construction regulator sponsor development of such a "library".

Engineers at Design Fire Consultants Ltd and researchers at The University of Edinburgh's Edinburgh Fire Research Centre (EFRC) have worked together to:

- Undertake a series of tests on a wide array of candidate ventilated rainscreen cladding assemblies;
- Analyse and present the results; and
- Show how these data may be used in support of an external wall assessment.

This report represents the second output from this project.

1. Aims and objectives

The project's aim is to generate a publicly available dataset that can be used by practitioners in support of external wall assessments.

To achieve this aim, the objectives of the project are as follows:

1. To design and fabricate a test assembly that allows different combinations of cladding and insulation materials and products to be tested in combination, in a ventilated rainscreen configuration.
2. To capture data to allow the potential hazards of combinations of products to be quantified.
3. To present the data in such a way that a suitably competent professional may use it in support of an external wall assessment.
4. To make the data freely and publicly available so that practitioners may make use of it and signpost practitioners to examples of how such data might be used.

This second report is intended to present the results and analysis. Full data sets are available online at the project's database website, which is freely and publicly accessible at https://claddingdata.dfc.co.uk.

2. Limitations of this work

The scope of this project is to investigate the fire hazards presented by different combinations of rainscreen cladding and insulation materials and products.

While the overall aim is to generate a dataset that has utility for fire safety practitioners, it must be acknowledged that the degree to which any test within this project may be compared against a real building is clearly limited. Indeed, the test results do not – and cannot – be precisely representative of a real building. Furthermore, the data generated in this project do not constitute classification results, and no pass/fail criteria are provided.

The data is only useful to the degree which a suitably competent professional believes they provide relevant insights about the potential fire hazards presented by any cladding system.

While the intent of this work is to provide information that may support competently performed external wall assessments, it is readily acknowledged that the data presented in this study will always be limited. In particular they are limited by the specific products that were tested and the scale at which they were tested. Readers must judge for themselves whether the data presented (in its context with other data) is relevant and useful for their particular circumstance, and the extent to which this is the case.

2.1. Disclaimer

Whilst the University of Edinburgh and Design Fire Consultants have used reasonable endeavours to ensure the accuracy of the information provided, no warranty is granted as to the accuracy of the information or for the use of the information. The University of Edinburgh and Design Fire Consultants accept no liability whatsoever in respect of any claim or claims arising from use by any third party of any such information. All conditions and warranties, express or implied, whether arising under statute or common law including, but not limited to, conditions and warranties as to quality, merchantability and fitness for purpose are hereby excluded.

3. Materials and products

To meet the objectives of this study, it is necessary to generate data about a range of different combinations of cladding and insulation materials and products. There are innumerable potential combinations that might be used, and therefore a limited number have necessarily been selected for this study, based on combinations that are frequently encountered in UK professional practice. In addition, some combinations of product types have been tested that do not reflect combinations that might be likely to be used in practice, but that provide potential additional insights for practitioners.

Each cladding material was paired with an opposing face (on the other side of the cavity). The three basic ventilated insulation types that would form the opposing face were identified as: mineral wool insulation (MW), phenolic foam (PF), and polyisocyanurate foam (PIR). In the context of the UK construction industry, PF and PIR are typically sold with foil ‘facers’, and mineral wool is typically sold (for ventilated rainscreen cladding applications) without foil facers. In addition to these insulations, tests were also performed using a water-cooled steel plate (WC) as the opposing face. These tests were performed with the intent of exploring the difference in burning behaviour that occurred when a cavity was present (i.e. the water-cooled steel plate as the opposing face) and when an insulated cavity was present (i.e. an insultation product as the opposing face).

The rainscreen cladding material/product types identified were follows: aluminium composite panels with a polyethylene core (ACM PE) or a mineral-filled core (ACM A2); oriented strand board (OSB); plywood; high pressure laminate (HPL); cedar board; solid aluminium; and brick. It was initially proposed to include aluminium composite panels with a modified core (ACM FR) and fire retarded HPL (HPL FR), however, the project team were unable to obtain these products from the UK marketplace within the timescales of the project.

The specific products that were obtained as part of this study are shown in Table 1. It should be noted that in selecting these specific products the authors are making no claims about the regulatory classifications of any of the products, nor the suitability of these products (or otherwise) for any application within the external wall system of a building.

In addition to these products, a mineral wool (MW/BC) was used as the ‘insulation’ product during the development of the test method and studies on cavity width. This product was selected for this purpose due to its relative convenience in terms of handling and post-test disposal.

Throughout this document, reference will be made to ‘combustible’ or ‘non-combustible’ products. This terminology is used as a shorthand rather than to indicate true non-combustibility. For example, mineral wool will be referred to as a non-combustible insulation – despite the presence of combustible binders within the product. Those products that will be termed non-combustible for the purposes of this document are indicated with an asterisk in Table 1/2. Similarly, the terminology used is not in accordance with any standardised classification methodology and does not indicate any regulatory status.

The testing matrix was comprised of combinations of these cladding and insulation products. Tests were performed in triplicate. It should be noted that in the case of the ACM PE experiments, only one test of each combination was performed as these were found to approach the maximum capacity of the extraction system in the laboratory. In addition, a sensitivity study was performed on the cavity width using an OSB, MW/BC combination; this combination of products was selected due to its relative convenience in terms of handling and post-test disposal.

Table 1. Product details. Note that in the case of the ACM products the assumed heat of combustion refers to the core (between the aluminium facer).

Product type		Product name	Product thickness	Bulk density (as measured)	Assumed ΔH_c
Aluminium composite material – polyethylene core	**ACM PE**	Reynobond	4 mm	1364	46.2 [5]
Aluminium composite material – A2 rated core*	**ACM A2**	Alpolic A2	4 mm	2059	3.4 [5]
Oriented strand board	**OSB**	OSB/3 BBA	11 mm	621	19.33 [6]
Plywood	**PLY**	F/E Plywood	12 mm	550	19.3 [6]
High pressure laminate	**HPL**	Online Plastics Group White HPL sheet	8 mm	1449	21.3 [5]
Cedar board	**CDR**	Canadian Western Red Cedar	12 mm	413	18
Aluminium plate*	**AL**	Aluminium sheet 1050A grade	2 mm	2659	-
Brick*	**BRK**	Red clay brick	102 mm	2101	-
Mineral wool*	**MW**	Rockwool RWA45	100 mm	47	-
Phenolic foam	**PF**	Xtratherm Safe-R Performance Phenolic	100 mm	39	26.46 [6]
Polyisocyanurate foam	**PIR**	Celotex GA4100	100 mm	31	28.32 [6]
Mineral wool*	**MW/BC**	Beamclad	25 mm	162	-
Water cooled steel plate*	**WC**	N/A	1.5 mm	N/A	-

Table 2. Testing matrix, with the number indicating the number of trials.

	Mineral wool*	PIR foam	Phenolic foam	Water-cooled steel plate*
ACM PE	1	1	1	-
ACM A2*	3	3	3	-
OSB	3	3	3	3
Plywood	3	3	3	3
HPL	3	3	3	3
Cedar	3	3	3	3
Aluminium*	3	3	3	-
Brick*	3	3	3	-

4. Results

The results are presented in three parts:

- A single experiment (OSB and Phenolic Foam – test code: 059_OSB_PF_02) is presented in detail to allow the format of the results and calculation procedures to be explained.
- The cavity width study is presented.
- All the data are presented.

The data is also available at https://claddingdata.dfc.co.uk. Appendix A of this report also highlights any experimental observations of particular note.

4.1. Single experiment

The progression of the experiment with OSB and PF is illustrated in Figure 2. During the experiment, it was observed that:

- After the burners ignited, flames from the propane were present on the outer surface of the cladding, the inner surface of the cladding, and at the base of the insulation.
- At around 40 s, it was observed that flame elongation occurred in the cavity on the surface of the OSB – this is attributed to ignition of the OSB.
- At around 1 min 40 s, flames were observed to reach the top of the cavity. At this time flame tips on the outside of the OSB only reached around one quarter of the way up the panel.
- At around 1 min 49 s, debris was observed to fall into the cavity – this is attributed to falling foil from the PF insulation.
- At round 3 min 20 s, flames on the outside of the OSB reached to approximately half-way up the panel.
- At around 4 min 15 s, flames on the outside of the OSB reached the top of the apparatus.
- At around 4 min 54 s, a vertical crack was observed in the lower part of the OSB panel.
- From around 6 min 40 s, a crack was observed to open across the height of the OSB.
- At 8 min 39 s, the OSB on the right fell away from its supporting frame.
- At 9 min 2 s, the OSB on the left fell away from its supporting frame.
- At 13 min 10 s, smouldering combustion was visible at the top of the insulation.
- At 17 min 20 s, flaming was visible at the top of the insulation.
- At 21 min 56 s, flaming was visible in the central region of the insulation.

The HRR data, and mass loss data for each of the scales is presented in Figure 1. The baseline heat release of the burners was subtracted from the HRR prior to plotting – this was found to be 8.5 kW. The peak heat release rate occurred at 5 min 49 s. The cladding and the insulation panels were supported independently. However, during the test the specimens often moved so that contact occurred between the test specimens – this meant that independent measurements were no longer possible. Each mass loss plot has been curtailed from the time at which contact occurred between specimens on the different balances.

Six metrics for quantifying aspects of the tests were identified as follows:

- Peak heat release rate (kW);
- Time to peak heat release rate (min);
- Peak rate of change of heat release rate, $\frac{d\dot{Q}}{dt}$ (kW/s);
- Time to peak rate of change of heat release rate (min);
- Total heat release (MJ); and
- Residual heat release rate at 30 minutes (kW) (averaged over the final minute of the test).

An illustration of the physical meaning of each metric is provided in Figure 3.

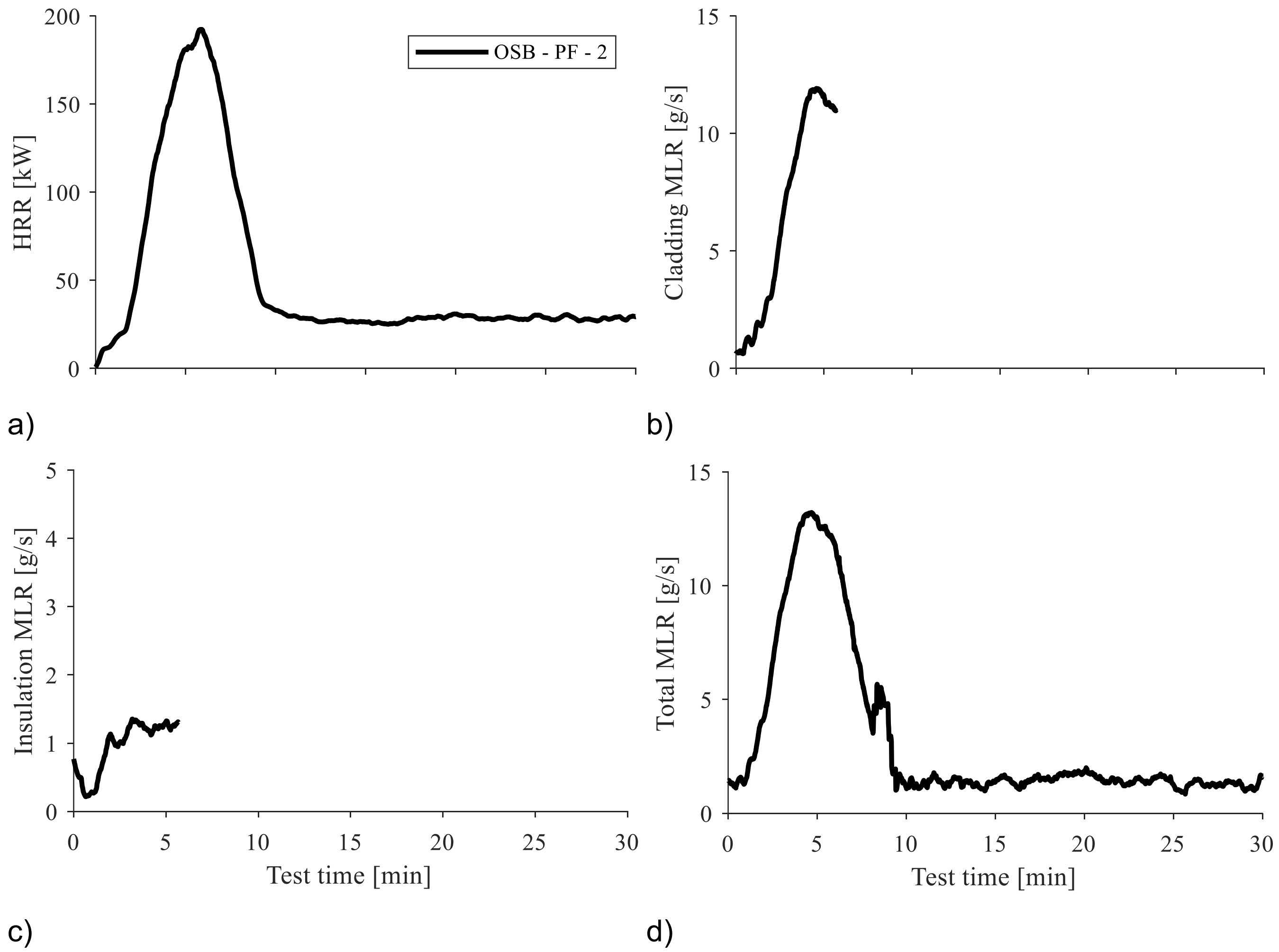
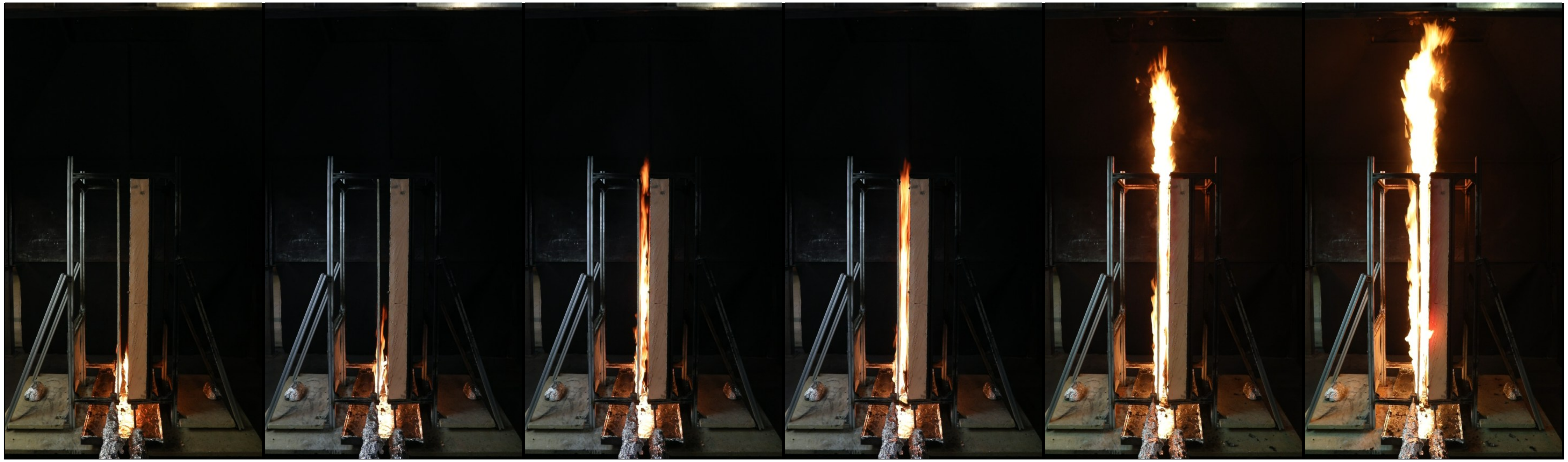
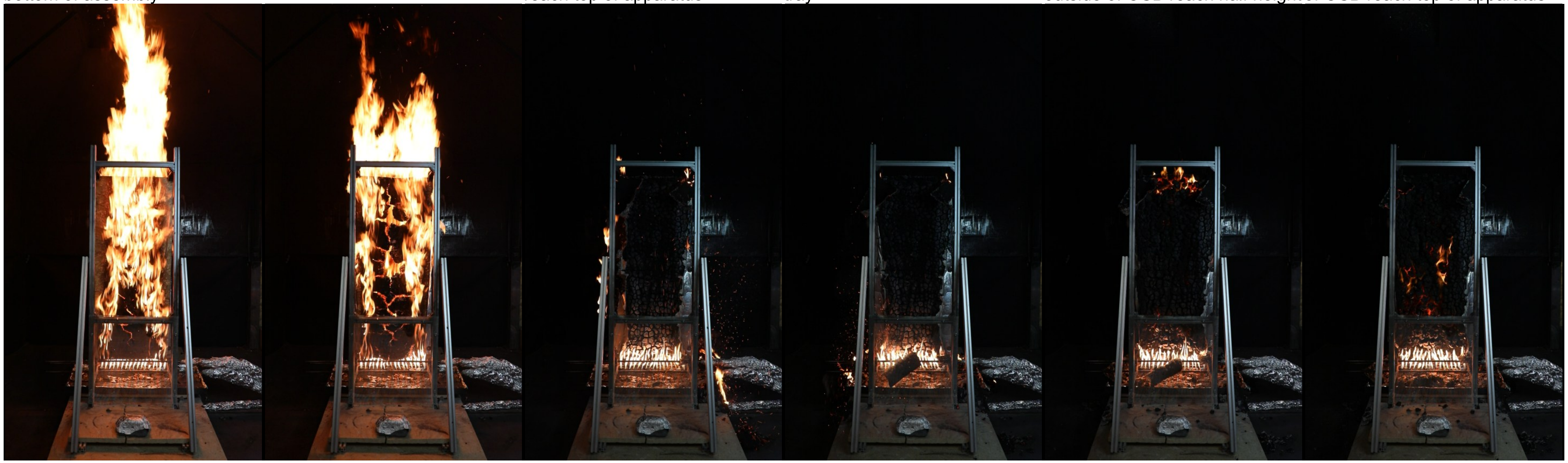


Figure 1. Experimental results for OSB PF 2: a) HRR, b) Cladding MLR, c) Insulation MLR, and d) Total MLR (note that MLR vertical axis scales are dissimilar).



a) 10 s – burners impinge at bottom of assembly | b) 40s – cavity flame extension | c) 1 min 40 s – flames in cavity reach top of apparatus | d) 1 min 49 s – debris falls into tray | e) 3 min 20 s – flames on outside of OSB reach half height | f) 4 min 15 s – flames on outside of OSB reach top of apparatus



g) 4 min 54 s – vertical crack opens at bottom of OSB panel | h) 6 min 40 s – crack observed across entire height of OSB | i) 8 min 39 s – OSB on right falls away from frame | j) 9 min 2 s – OSB on left falls away from frame | k) 17 min 20 s – smouldering and flaming at top of phenolic panel | l) 21 min 56 s – smouldering and flaming in centre of phenolic panel

Figure 2. Photographs of key moments during an experiment on OSB and PF.

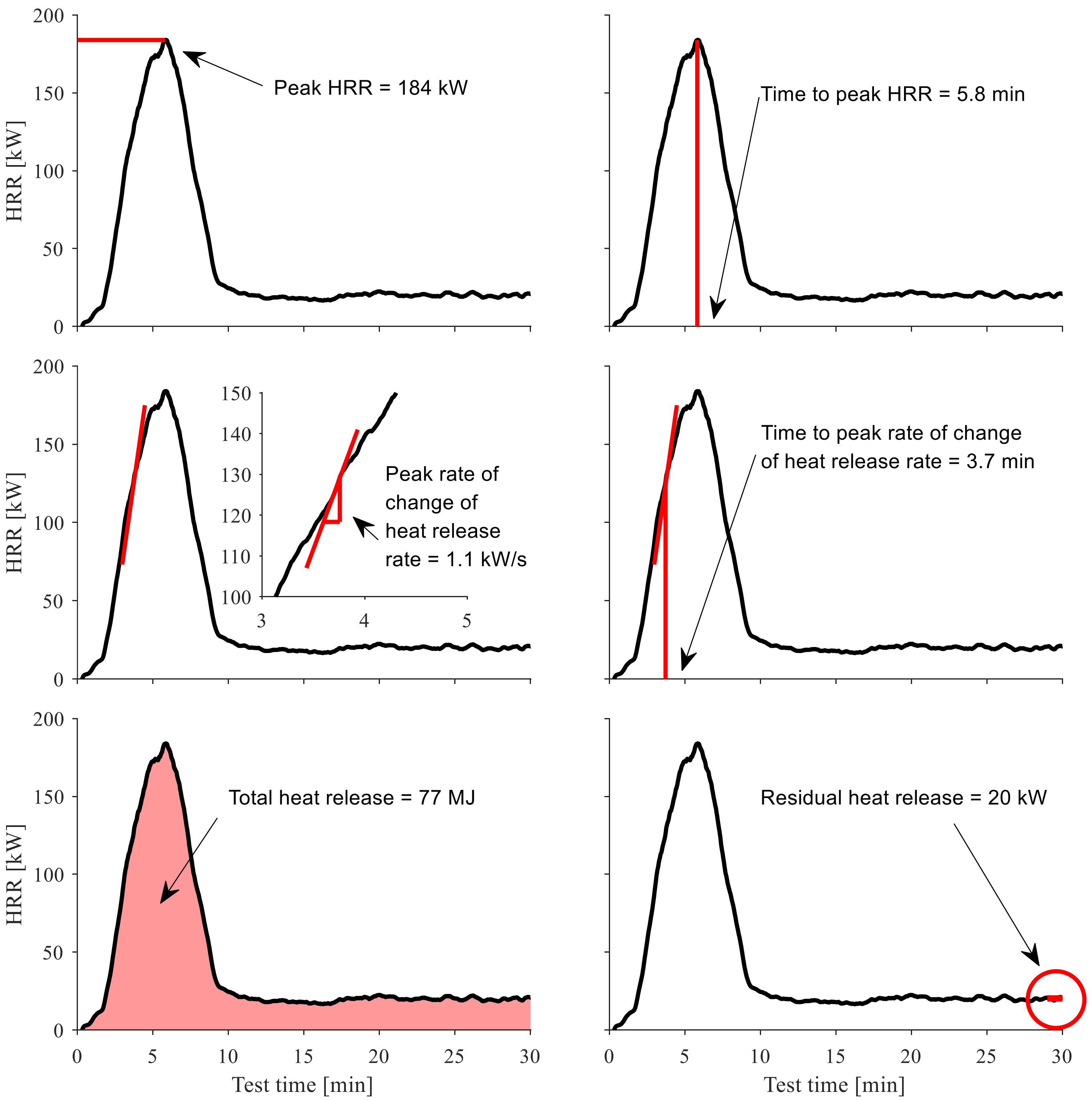
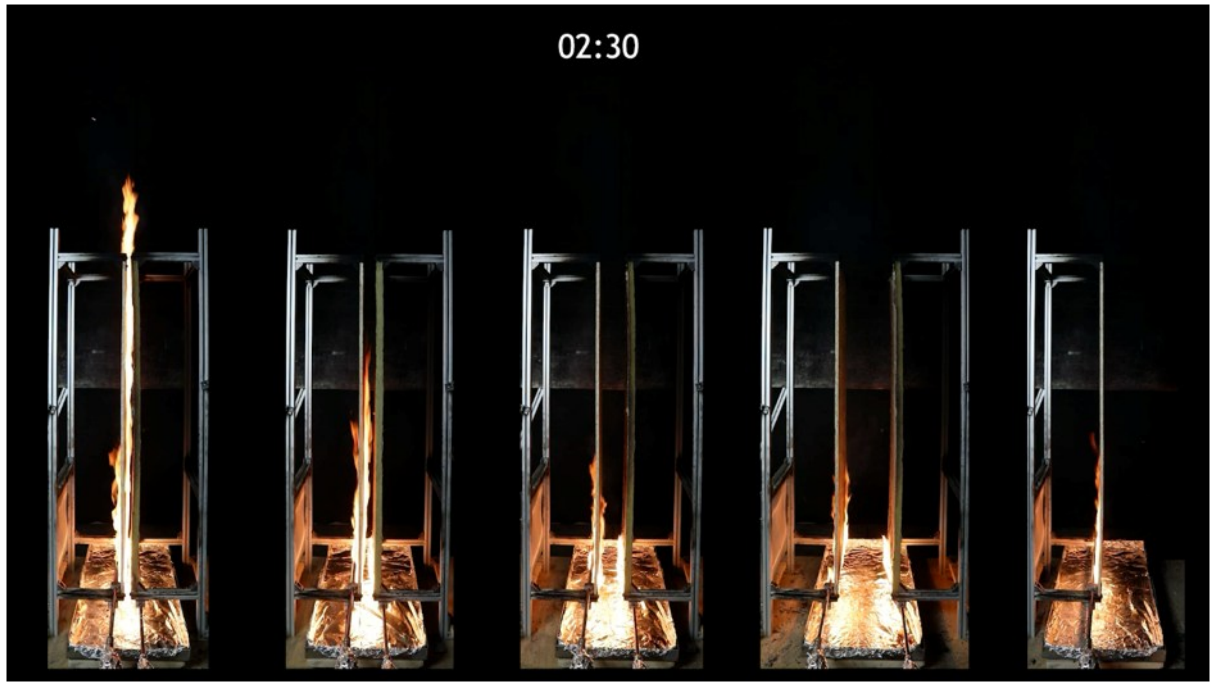


Figure 3. Illustration of metrics.

4.2. Cavity study

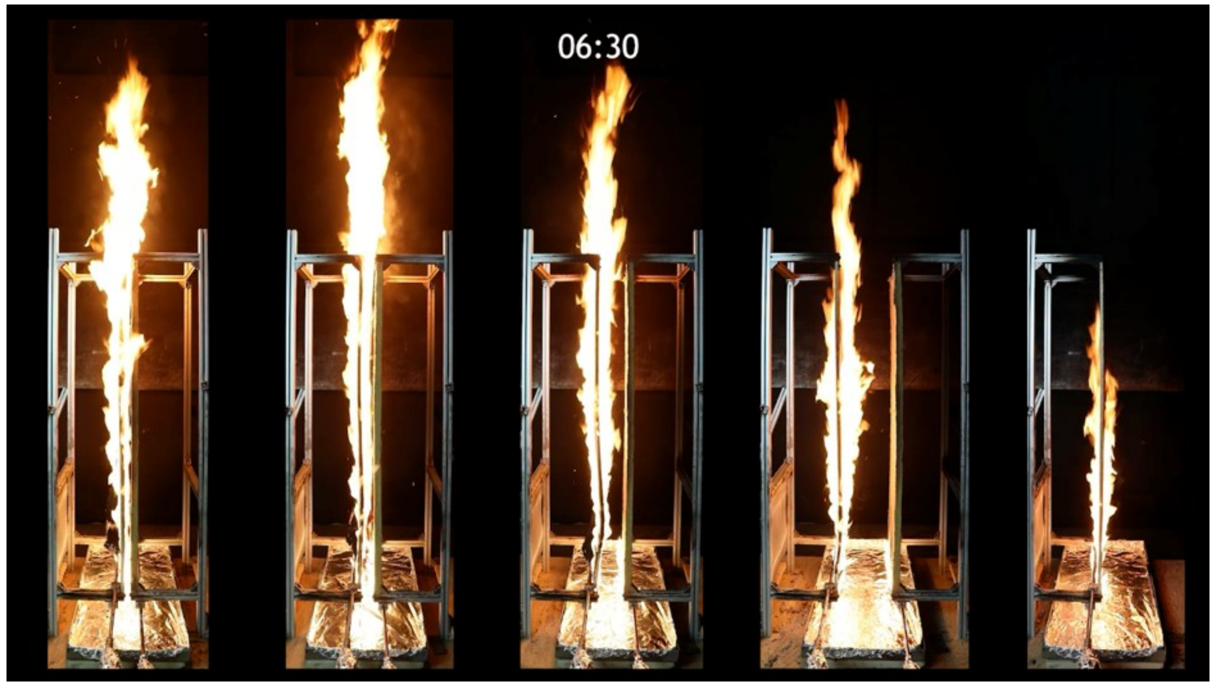
To determine the cavity width that would be used throughout the study, experiments were performed on a system containing Oriented Strand Board (OSB) as the rainscreen cladding panel, and mineral wool (MW) as the backing insulation. Cavity widths were varied from 25 mm to 200 mm, with an additional configuration performed without any insulation panel present – this is referred to as the 'no insulation' case. All of these configurations were tested in triplicate.

Figure 4 shows images of each experiment at 2 min 30 s, and Figure 5 shows images of each experiment at 6 min 30 s – the latter coincides with the peak of the HRR for the 25 mm case.



25 mm 50 mm 100 mm 200 mm No insulation

Figure 4. Photographs of flame extensions in cavity width experiments at 2 min 30s.



25 mm 50 mm 100 mm 200 mm No insulation

Figure 5. Photographs of cavity width experiments at peak HRR for 25 mm case.

The heat release data for the first trial of each width is illustrated in Figure 6.

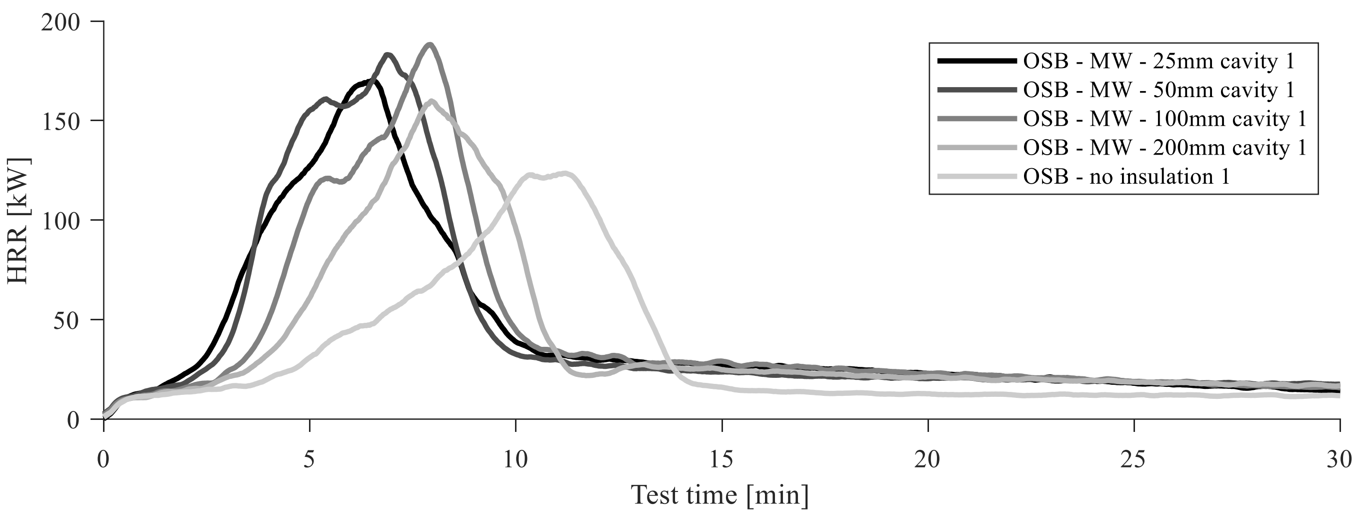
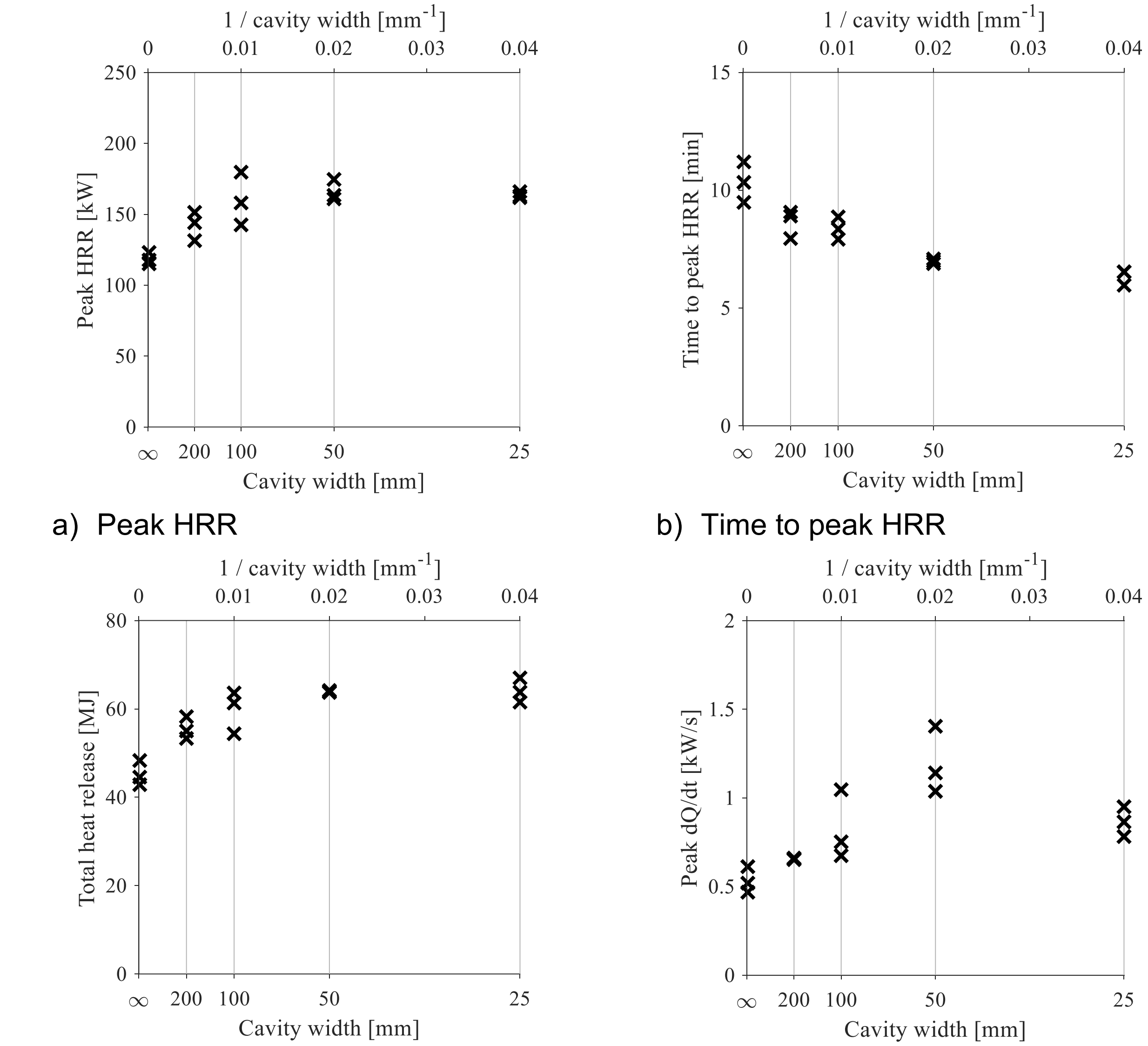


Figure 6. Heat release rate results versus time for cavity width sensitivity study.

Each of the metrics are provided in Table 3 and are plotted with respect to the inverse of the cavity width in Figure 7. The no insulation case is presented as 1/width = 0.

Table 3. Cavity width study comparative metric results.

Cavity Width	Peak HRR [kW]	Time to Peak HRR [min]	Peak $\frac{d\dot{Q}}{dt}$ [kW/s]	Time to Peak $\frac{d\dot{Q}}{dt}$ [min]	Total HR [MJ]	Residual HRR [kW]
25	162	6.53	0.86	4.37	61.5	5.97
	163	5.97	0.78	6.08	63.8	5.56
	166	6.53	0.95	4.48	67.0	7.80
50	175	6.88	1.40	4.53	63.9	9.31
	163	7.08	1.14	4.83	63.7	6.18
	161	6.98	1.04	5.00	64.2	7.03
100	180	7.92	1.05	5.52	61.3	7.56
	143	8.87	0.75	5.83	54.4	4.89
	158	8.35	0.67	5.87	63.6	10.7
200	151	7.95	0.66	8.25	55.0	8.55
	144	8.90	0.66	8.47	58.2	8.17
	131	9.07	0.65	8.32	53.3	6.75
No insulation	115	11.2	0.52	10.7	42.9	3.26
	123	10.3	0.47	9.23	48.3	8.50
	118	9.48	0.61	9.53	44.5	6.26



a) Peak HRR
b) Time to peak HRR
c) Total heat release
d) Peak $\frac{d\dot{Q}}{dt}$

Figure 7. Sensitivity study comparative metric results versus cavity width.

For these parameters, it can be seen that the ‘no insulation’ case resulted in a slower fire growth and a lower peak heat release rate than the other configurations. As the cavity was introduced, the peak heat release rate increased. This trend in increasing peak HRR was not found to continue for cavity widths less than 100 mm. Similarly, the other metrics showed relatively large changes as the cavity width was increased above 100 mm, compared to relatively small changes when the cavity width was decreased below 100 mm.

This suggests that for the chosen scale of test (i.e. height and width of cavity):

1. The results are relatively insensitive to changes in the cavity width below 100 mm; and
2. The most extreme behaviours are observed when the cavity width is below 100 mm – e.g. the PHRR is higher, the time to PHRR is shorter.

On this basis, the project team took a decision to proceed with a 50 mm cavity width for the remainder of the study. In selecting this value, it is recognised that a different cavity width would yield different absolute values for this study. However, the potential utility of the results of this work is in comparison across the study, rather than the absolute values delivered by any particular test.

4.3. All tests

Selected images from the moment of peak heat release rate for a range of exemplar tests are shown in Figure 8. This gives an indication of the range of behaviours that were observed across the study. The heat release rate data for all of the tests is provided in Figure 9, and a table of all of the various metrics is provided in Table 4.

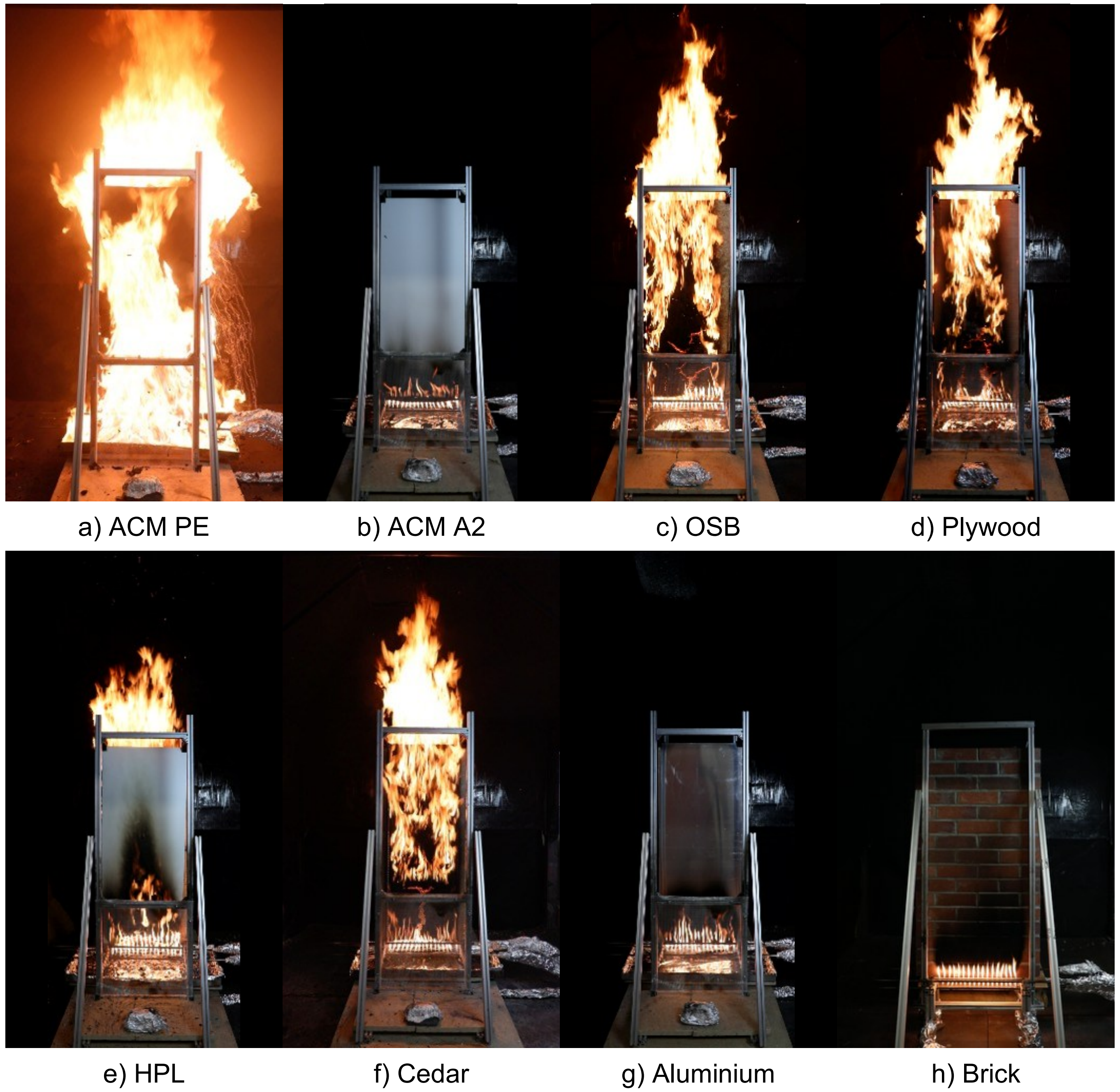


Figure 8. Photographs of various cladding panel experiments at their peak HRR.

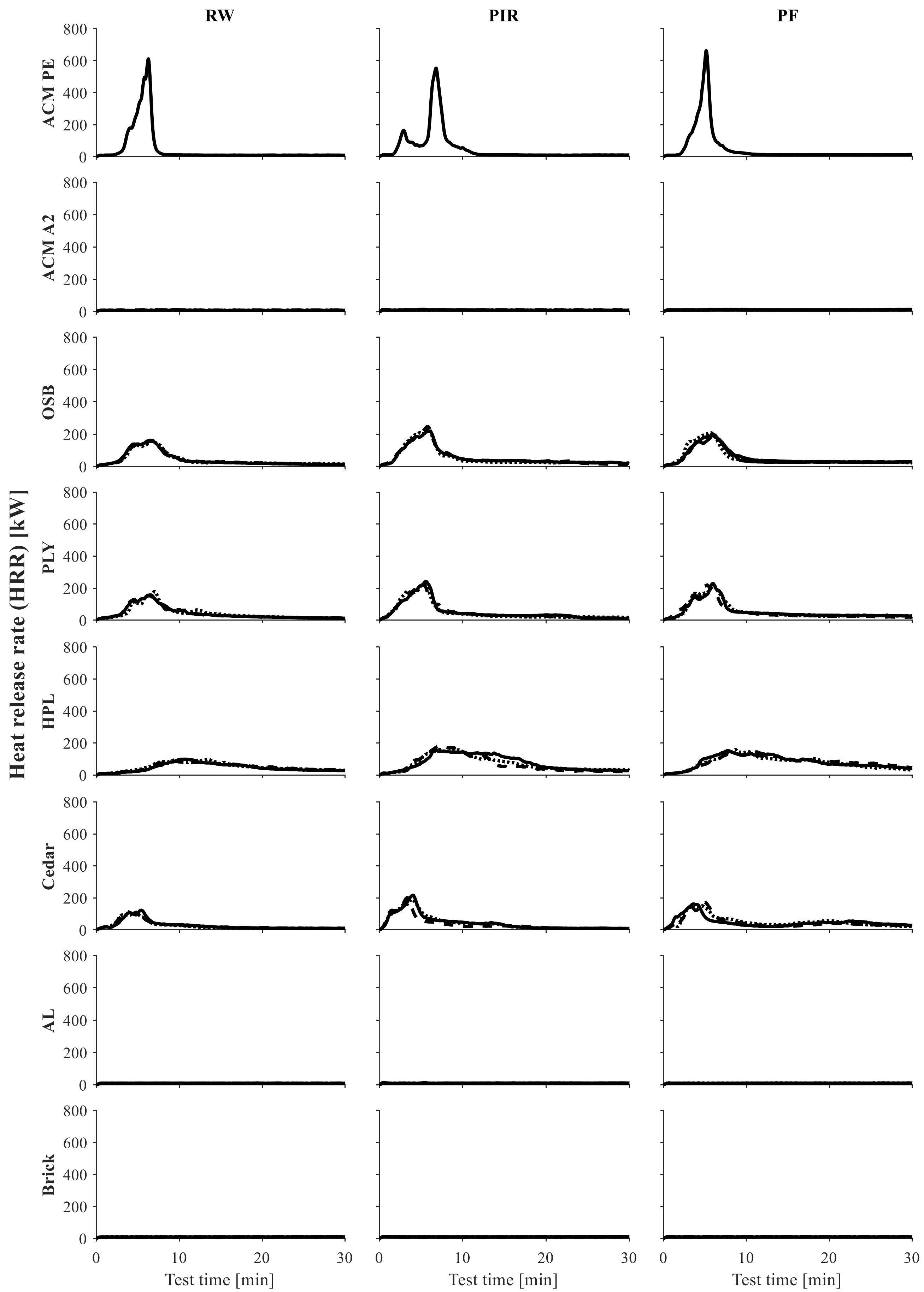


Figure 9. Heat release rate results for tested systems.

Table 4. Summary of comparative metrics (averaged across the three repeats for all but ACM PE cases), with standard deviation in parentheses.

Cladding	Insulation	Peak HRR [kW]	Time to Peak HRR [min]	Peak $\frac{d\dot{Q}}{dt}$ [kW/s]	Time to Peak $\frac{d\dot{Q}}{dt}$ [min]	Total HR [MJ]	Residual HRR [kW]
ACM PE	MW	603	6.27	5.21	6.83	67.9	1.5
	PIR	545	6.8	8.2	7.25	75.8	2.34
	PF	654	5.15	7.37	5.72	74.6	5.56
ACM A2	MW	1.16 (2.01)	9.52 (0)	0.0227 (0.0393)	10.1 (0)	0.0282 (0.0488)	0.535 (0.496)
	PIR	5.07 (1.07)	2.08 (2.78)	0.145 (0.0285)	1.03 (0.0601)	0.551 (0.604)	0.9 (1.03)
	PF	5.6 (0.886)	22.6 (11.7)	0.0559 (0.0121)	15.3 (12.6)	1.59 (0.688)	4.08 (1.69)
OSB	MW	152 (3.58)	6.73 (0.262)	1.22 (0.016)	4.64 (0.184)	59.6 (1.41)	5.52 (1.37)
	PIR	224 (13.3)	5.91 (0.111)	1.25 (0.0817)	3.24 (0.356)	83.1 (3.31)	8.92 (4.8)
	PF	191 (7.66)	5.82 (0.192)	1.45 (0.449)	3.95 (0.493)	78.7 (2.19)	18.4 (2.88)
	WC	101 (6.09)	8.53 (0.0726)	0.494 (0.0452)	7.22 (1.59)	45 (3.32)	6.84 (1.88)
Plywood	MW	156 (12.9)	6.56 (0.386)	1.33 (0.144)	4.74 (0.276)	60.6 (0.211)	4.63 (0.454)
	PIR	220 (11.7)	5.41 (0.17)	1.29 (0.363)	3.53 (1.05)	74.8 (2.48)	5.16 (3.23)
	PF	213 (7.08)	5.75 (0.436)	1.56 (0.295)	5.44 (1.23)	79.8 (3.04)	15.4 (4.11)
	WC	50.9 (15.2)	8.64 (1.22)	0.264 (0.0506)	7.74 (1.94)	18.7 (4.2)	2.79 (0.436)
HPL	MW	86.3 (6.48)	11.1 (2.24)	0.414 (0.0709)	7.76 (0.0674)	73 (4.12)	21.2 (1.79)
	PIR	156 (13.2)	7.03 (0.312)	0.976 (0.137)	6.05 (1.15)	111 (7.41)	18.7 (5.77)
	PF	144 (7.41)	9.21 (1.79)	0.714 (0.317)	7.23 (1.62)	128 (5.3)	33.1 (7.97)
	WC	7.33 (1.17)	10.3 (2.41)	0.0452 (0.00544)	9.62 (6.25)	3.47 (0.143)	1.33 (0.38)
Cedar	MW	107 (7.08)	4.47 (0.934)	1.05 (0.0842)	3.77 (0.375)	32.5 (2.93)	1.56 (0.669)
	PIR	194 (13.5)	3.73 (0.369)	1.71 (0.198)	1.86 (0.0347)	57.2 (7.89)	1.07 (0.392)
	PF	155 (8.78)	4.06 (0.819)	1.52 (0.365)	2.97 (0.853)	73.9 (4.71)	17.6 (4.39)
	WC	23.4 (3.87)	6.44 (0.896)	0.143 (0.0109)	5.89 (0.898)	8.03 (2.95)	1.51 (0.333)
AL	MW	0 (0)	-	0 (0)	-	0 (0)	1.57 (0.659)
	PIR	5.45 (1.01)	2.17 (2.84)	0.167 (0.0104)	1.01 (0.0347)	0.299 (0.192)	2.09 (0.528)
	PF	1.17 (2.03)	13.6 (0)	0.0322 (0.0558)	1.03 (0)	0.354 (0.613)	2.17 (0.767)
Brick	MW	0 (0)	-	0 (0)	-	0 (0)	1.99 (0.399)
	PIR	3.37 (0.502)	0.567 (0.05)	0.111 (0.0215)	1.02 (0.00962)	0.0494 (0.0574)	1.88 (0.477)
	PF	2.86 (2.49)	26.7 (4.37)	0.0634 (0.0575)	1.04 (0.0118)	1.94 (2.47)	3.17 (1.36)

5. Analysis

The metrics presented in Table 4 can be plotted to allow their relative magnitudes to be compared. The data has been ranked in order from 'worst' to 'best'. Figure 10, Figure 11, and Figure 12 show each of the metrics with the data rank-sorted as appropriate. It should be noted that the order in which the cladding systems are presented in respective plots changes between the different metrics.

This analysis highlights some potentially useful information, but also illustrates the limitations of any single fire hazard parameter as a metric of hazard:

HRR. ACM PE gives the highest heat release rate (approximately 2-3 times the next 'worst'). When each insulation is paired with non-combustible claddings, the peak HRR is very low.

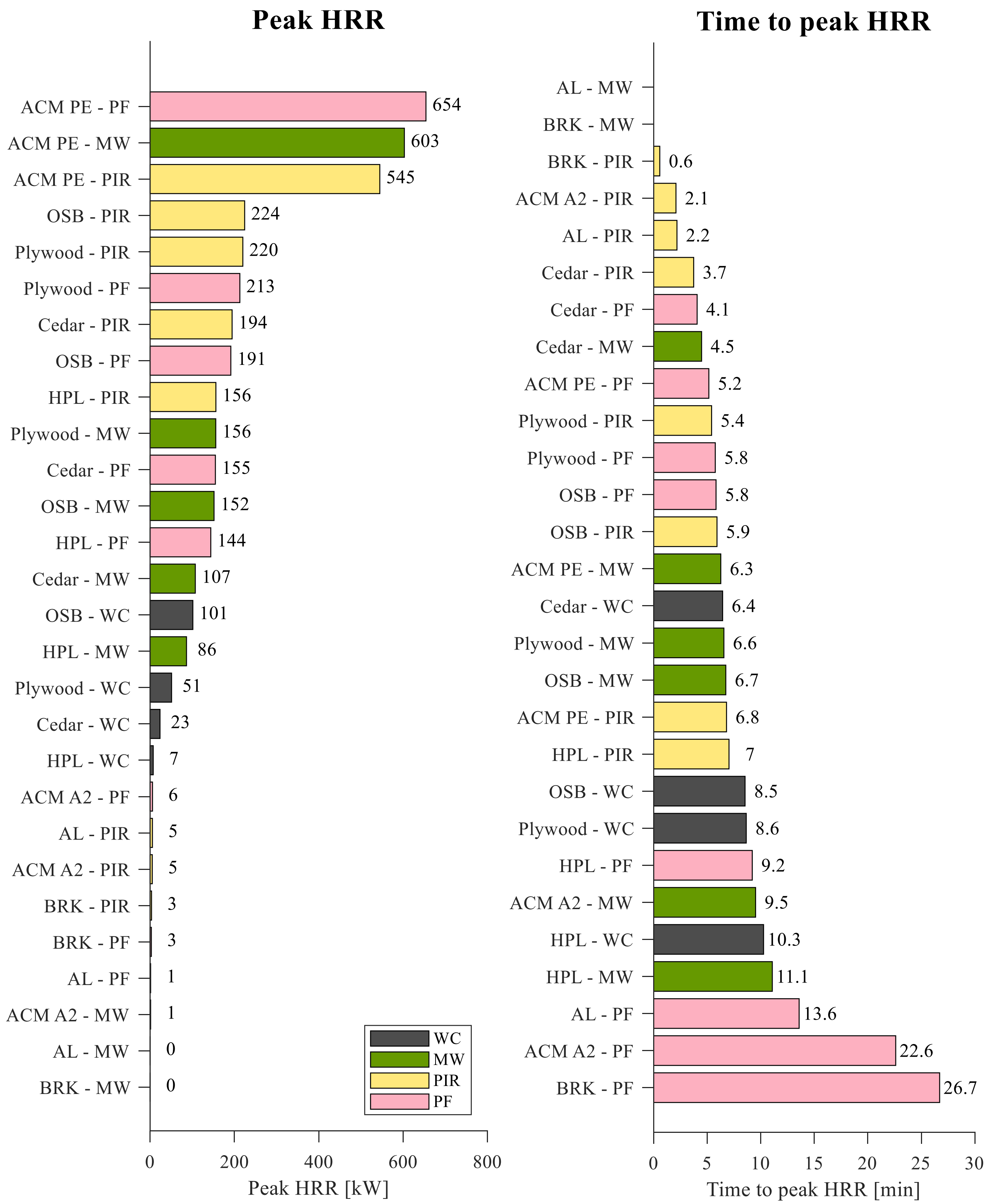
Time to peak HRR. The peak HRR is early for PIR insulation when paired with ACM A2 or Aluminium. However, it should be noted that in these cases, the peak HRR was relatively low (5 kW or less). The time to peak HRR data shows that the cedar board peaks much earlier than other timber based products – this is likely due, at least in part, to the relatively low density of the cedar board, thereby promoting rapid fire spread.

Peak rate-of-rise. This data again shows that the ACM PE is by far the 'worst' (more than double) of the various cladding products, and that the fire grows much more rapidly than for the other systems.

Time to peak rate-of-rise. The time to peak rate-of-rise also shows that systems with PIR insulation presented the earliest peak fire growth rate. Time to peak rate-of-rise was observed to occur more rapidly for cedar and for OSB or Plywood, with HPL taking even longer.

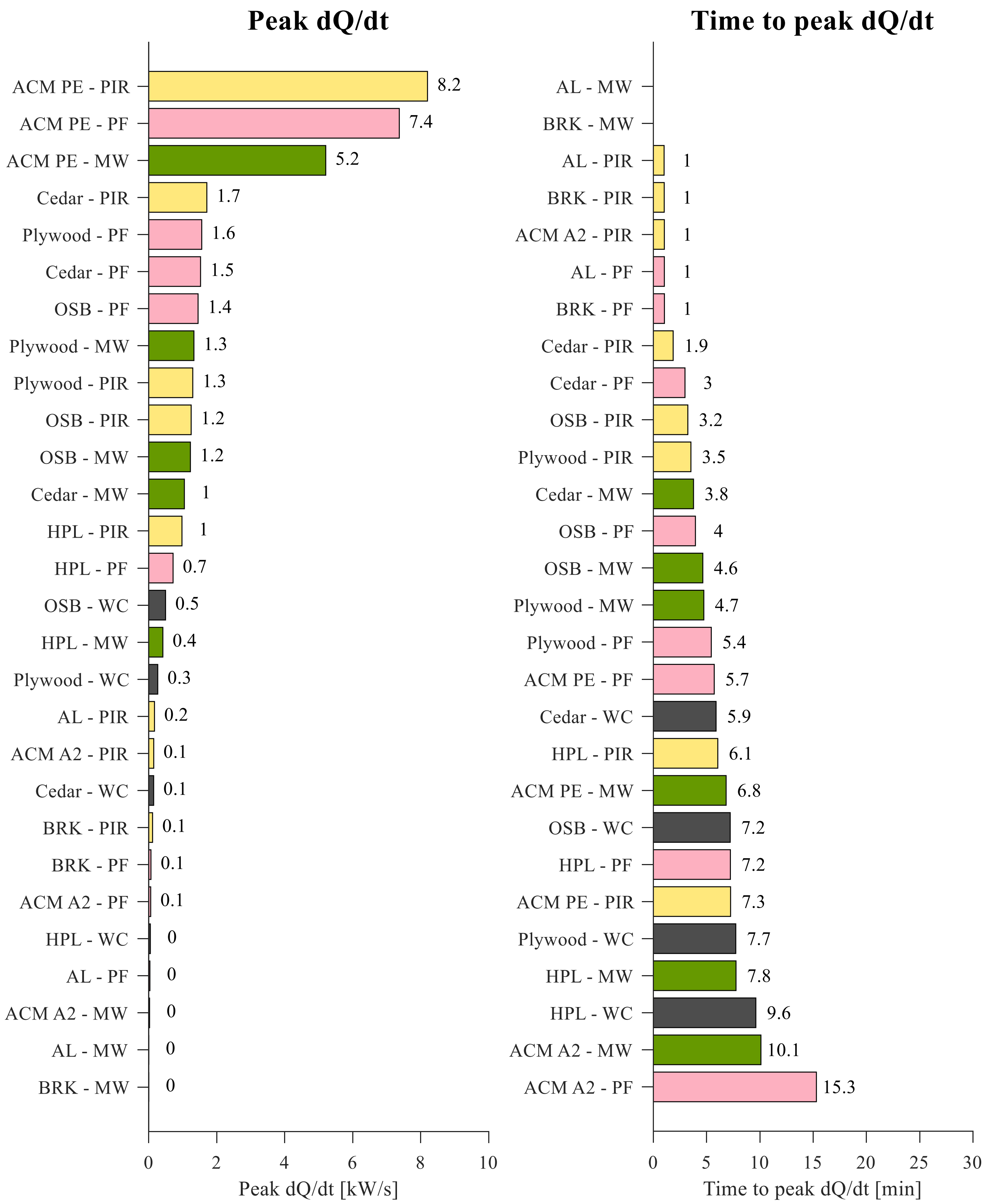
Total heat release. The system that released the most energy overall was HPL paired with PF; this is perhaps unsurprising, as the HPL has the greatest mass (and therefore greatest available energy) of the cladding products used. Non-combustible products such as ACM A2 and aluminium, even when paired with PIR or PF, released relatively little energy over the duration of the test (~1 MJ in total).

Residual heat release rate. The residual heat release rate at the end of the 30 minute experiments showed that HPL systems continued to release energy as smouldering combustion continued. Systems with PF insulation also presented the greatest residual HRR as the PF foam continued smouldering in addition to ongoing combustion of the remaining cladding.



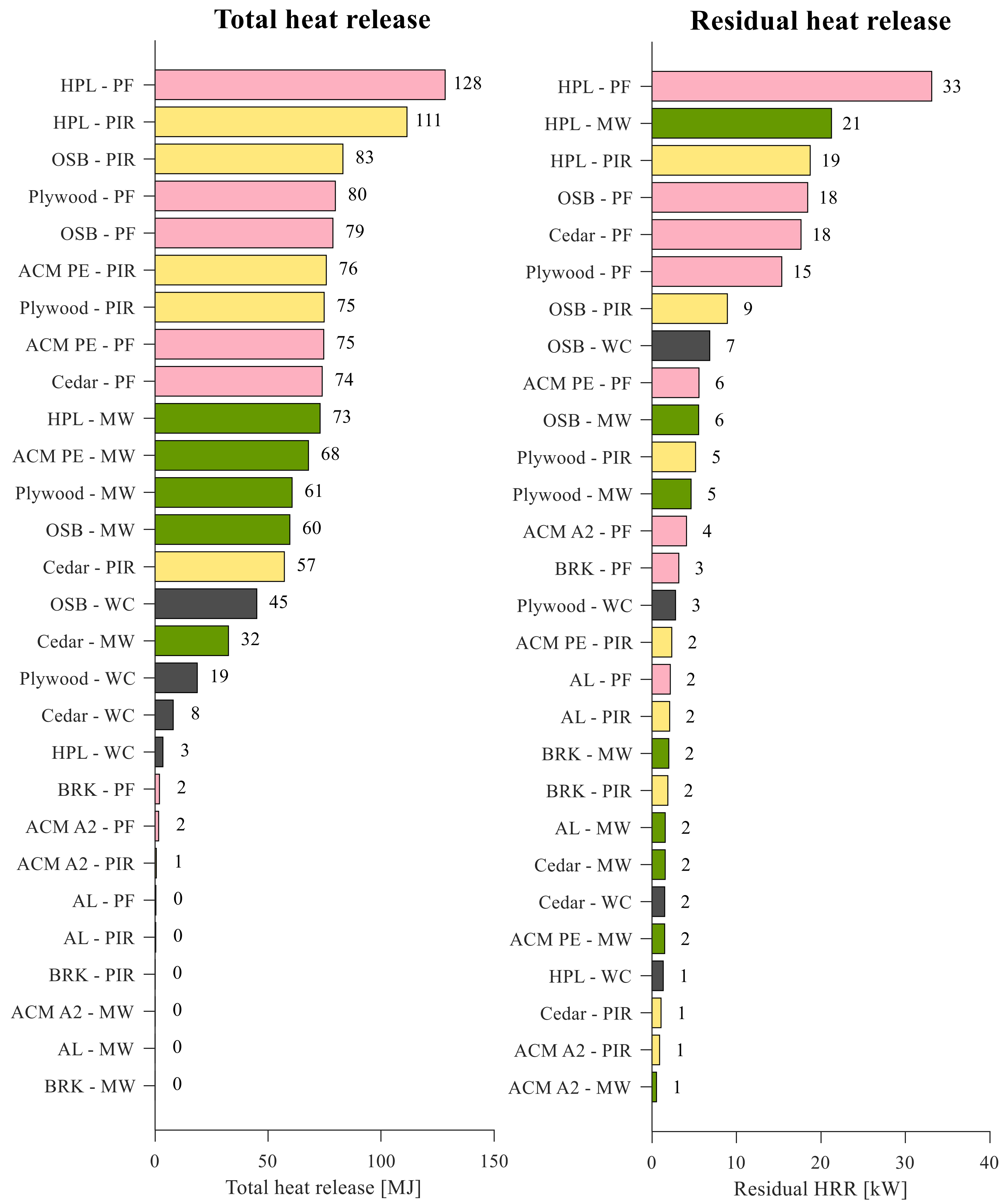
a) b)

Figure 10. Comparative metrics: a) Peak HRR, b) Time to peak HRR.



a) b)

Figure 11. Comparative metrics: a) Peak $\frac{d\dot{Q}}{dt}$, b) Time to peak $\frac{d\dot{Q}}{dt}$.



a) b)

Figure 12. a) Total heat release, b) Residual HRR.

5.1. Effect of the insulation

To quantify how the insulation products affected the fire behaviour of the systems, a series of experiments were performed where a cladding panel was paired with an opposing face comprised of a water-cooled steel panel. These experiments were performed for the OSB, PLY, HPL, and Cedar claddings. Each metric was then normalised with respect to the water-cooled steel panel case so that the relative increase due to each insulation product could be measured.

As an example, the normalised peak HRR for OSB cladding is presented in Figure 13. Any value above 1.0 indicates a relative increase caused by the presence of an insulation. The hatched area shows the additional increase due to the presence of each of the combustible insulation products.

- OSB with a water-cooled steel plate as the opposing face resulted in a peak HRR of 101 kW.
- When the opposing face was changed from a water-cooled plate to a mineral wool insulation (MW), the resulting peak HRR increased to 152 kW – a factor of 1.5 times.
- When the opposing face was instead changed to a PIR insulation, the resulting peak HRR was 224 kW – a factor of 2.2 times.
- When the opposing face was changed from a water-cooled plate to a PF insulation, the resulting peak HRR was 191 kW – an increase of 1.9 times.

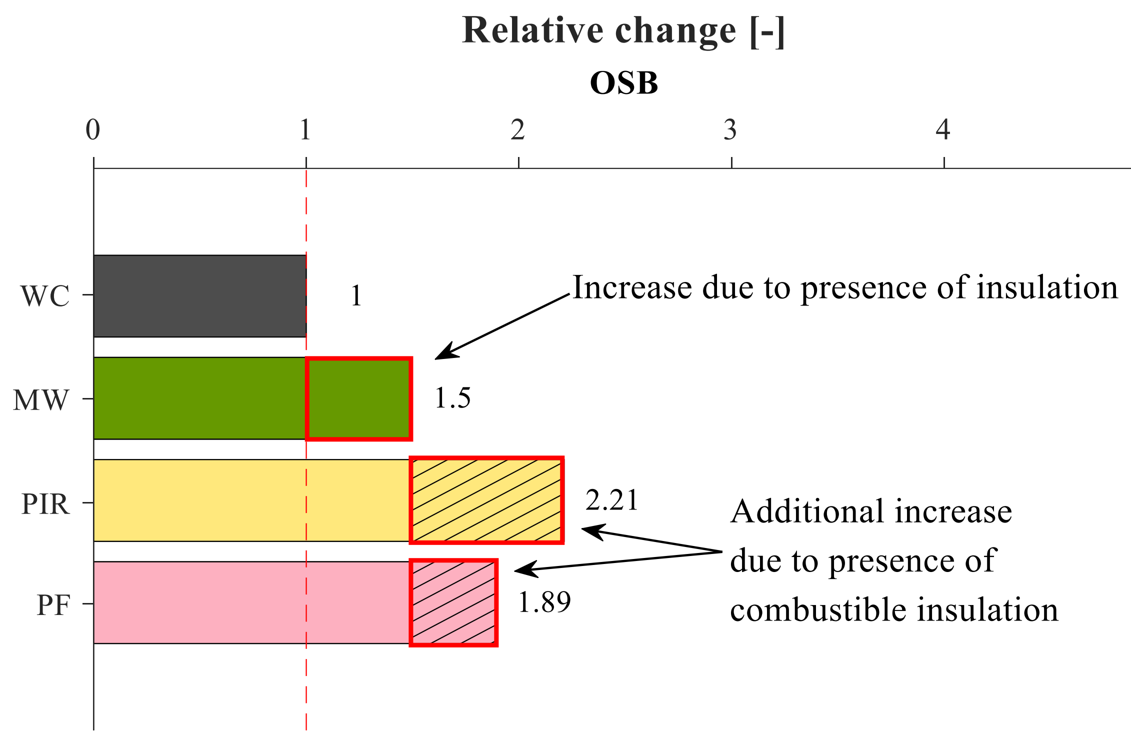


Figure 13. Illustration of change in peak HRR for OSB systems.

The relative change in each metric for OSB, PLY, HPL, and Cedar is illustrated in Figure 14. Overall, when compared against an opposing face comprised of a water-cooled steel plate, the presence of the mineral wool insulation product increased the peak HRR by between 1.5 times and 11.8 times (OSB and HPL respectively). The presence of a PIR or PF insulation increased the heat release rate by between 1.9 times and 21.3 times (OSB and HPL respectively).

Comparison of the MW results against the PIR and PF cases shows the presence of a combustible insulation always resulted in an increase in peak HRR. On average it was found that additional increase in peak HRR when combustible insulation was present was 0.8 times that when only insulation was present (i.e. if the increase was 100 kW due to insulation, the total increase was 180 kW with combustible insulation). However, the average data hides the wide range of results for the different claddings and insulations – with the additional increase due to combustible insulation varying between 0.5 and 1.5 times the increase for the non-combustible insulation case.

With the notable exception of the HPL case, time to peak HRR occurred more quickly for the MW case, and more quickly still for the PIR and PF cases. On average, the magnitude of the reduction in time to peak HRR when combustible insulation was present was 0.4 of the magnitude change when only insulation was present. Notably, the presence of MW increased the time to peak HRR for the HPL case, but the time decreased when a combustible insulation was used – HPL was therefore excluded from the above average.

In the case of the HPL, the presence of the insulations (when compared to an opposing face of a water-cooled steel plate) increased the total HR by between 21 and 37 times. On average across all cases, the magnitude of the additional increase in total HR when combustible insulation was present was 1.1 times the increase when only non-combustible insulation was present.

The peak rate-of-rise was greater for the MW case, and greater still for the PIR and PF cases. On average, the additional increase in the peak rate-of-rise due to the presence of combustible insulation was 0.5 times that when only non-combustible insulation was present.

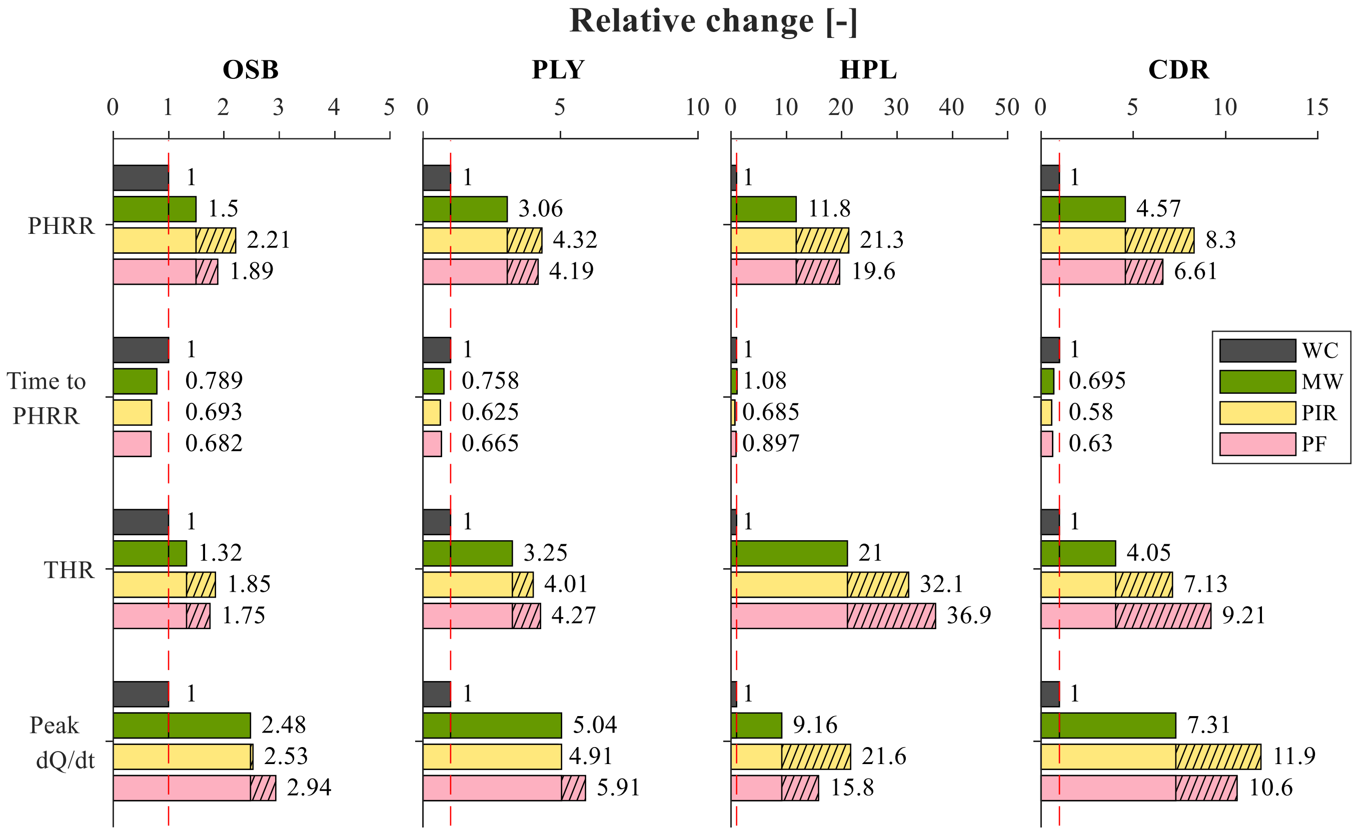


Figure 14. Change in metrics based on insulation type relative to a water-cooled steel panel insulation. Hatched area indicates additional increase due to presence of combustible insulation.

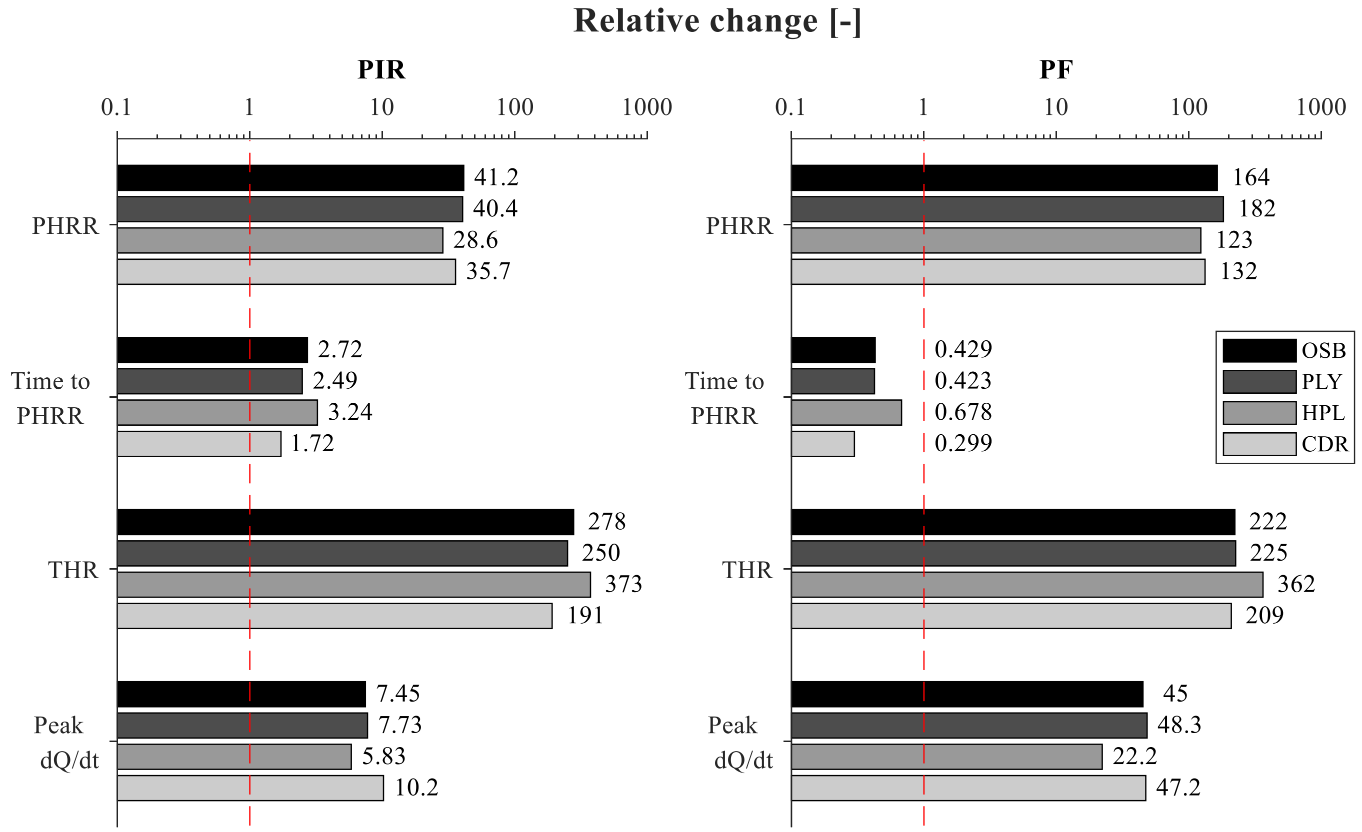


Figure 15. Change in metrics based on cladding type relative to its pairing with aluminium cladding.

5.2. Effect of the cladding

To quantify how the cladding products affected the fire behaviour of the systems, each metric was normalised with respect to the aluminium panel paired with PIR or PF. It was not useful to normalise with respect to the aluminium paired with MW case as no heat release above the baseline was measured.

It should be noted that, for this normalisation, the denominator value was small (e.g. between 1 kW and 5 kW) compared to the values used in Figure 14 (7, 23, 51, or 101 kW as appropriate). Nevertheless, this comparison allows for the change due to the presence of combustible cladding to be quantified. The relative change in each metric is illustrated in Figure 15 (with log scale).

It was found that with the addition of a combustible cladding (not including ACM PE): the peak HRR increased between 28 and 182 times; time to peak HRR was slightly shorter for the PF, and slightly longer for the PIR; total heat release was between 191 and 373 times greater; and the peak rate-of-rise was between five and fifty times faster. These metrics indicate that, compared to the case where a non-combustible cladding is paired with PIR or PF – the use of a combustible cladding causes a very significant change across most of the metrics.

5.3. Statistical correlation between metrics

Links between the comparative metrics can be investigated by performing a statistical correlation between the metrics. This way, any relationship between the parameters, and any relationship between the behaviours that they represent, can be viewed. This helps to establish whether a single metric may be used as a proxy for other metrics.

Pearson's correlation was performed between the various metrics, and the results are shown in Figure 16 – where a value of 1 would imply a perfect positive correlation between the two metrics, a value of 0 would imply no correlation, and a value of -1 would imply a perfect negative correlation.

For the investigated metrics, it can be observed that the peak HRR and the peak rate-of-rise of HRR $\frac{d\dot{Q}}{dt}$ has a strong correlation of 0.95. This suggests that the peak fire growth rate is linked to the peak fire size – which is unsurprising given that rapid fire growth will tend to result in a relatively high heat release rate.

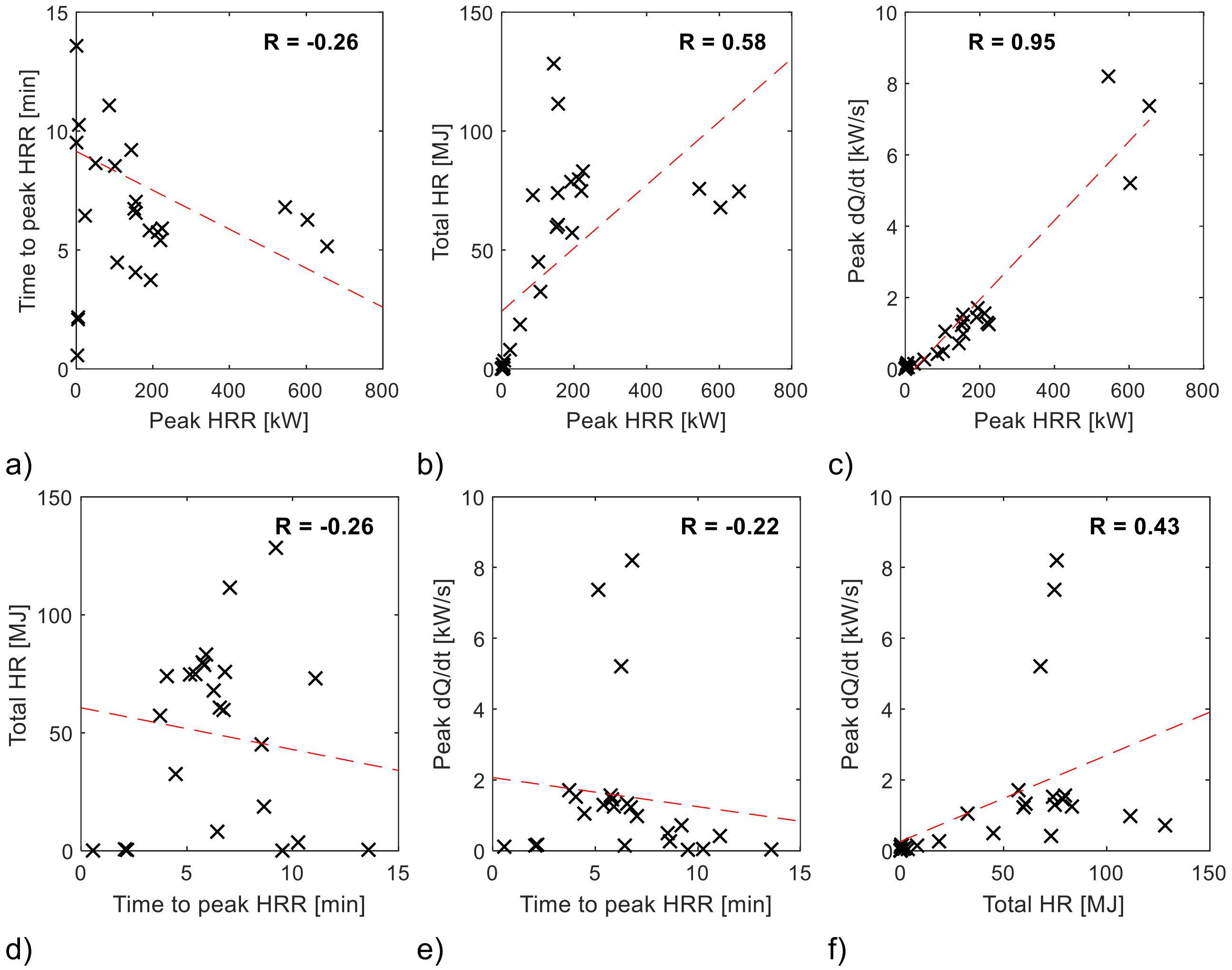


Figure 16. Pearson's correlation between comparator metrics.

The peak HRR is also somewhat correlated to the total heat release, with a value of 0.58. This correlation appears to be stronger for the products with low peak and total heat releases, and for the 'engineered woods'. Outliers from the correlation are the systems with HPL and ACM PE cladding panels. It appears that the higher total heat release from HPL and low peak HRR due to the high density of the product causes these systems to not correlate in the same manner as the other systems. Similarly with ACM PE systems, the relatively high peak fire size, but relatively low total heat release presents itself as an outlier from the other systems.

There is no apparent correlation between the other comparative metrics.

These correlations indicate that while observing and comparing using a singular metric can be useful, a single metric clearly cannot fully encompass the differences in burning behaviour presented by the various cladding systems. For any particular use scenario, one metric may be more useful than another.

6. Conclusions

A parallel panel apparatus (1.2 m high and 0.5 m wide) was created to allow a dataset to be generated to compare the fire behaviours of a range of cladding systems with dissimilar combinations of cladding and insulation. Ninety-four experiments were performed on thirty-three different systems combining different cladding and insulation products. It was found that:

- Systems including ACM PE were by far the 'worst' analysed – with the biggest fire and the fastest rate-of-rise.
- It was possible to differentiate across a range of metrics and place each system within the context of other pairs of cladding and insulation.
- The presence of a combustible cladding (i.e. the rainscreen) resulted in a greater comparative increase in peak HRR and total HR than the increase which occurred when those claddings were paired with a PIR or PF insulation.
  - When a non-combustible cladding was swapped to a combustible cladding (e.g. aluminium to OSB) this resulted in a 28-182 times greater peak fire size (for PIR or PF insulation).
  - When an opposing face of a water-cooled steel plate was changed to a PIR insulation, this resulted in a 2.2 times greater peak fire size (when paired with OSB cladding).
- When comparing the influence of combustible insulation vs. non-combustible insulation on each of the metrics, there is some variation across the difference cases. Nevertheless, averages show that:
  - The magnitude of the increase in peak HRR due to the presence of insulation was greater than the *additional* increase when a combustible insulation was present.
  - The magnitude of the reduction in time to peak HRR due to the presence of insulation was greater than the *further* reduction when combustible insulation was present.
  - The magnitude of the increase in total HR due to the presence of insulation was *less* than the *additional* increase when combustible insulation was present.
  - The magnitude of the increase in peak rate-of-rise due to the presence of insulation was greater than the *additional* increase when combustible insulation was present.
  - Residual burning of some systems continued long after peak HRR – both HPL and PF were observed to smoulder at the end of the experiments, regardless of their system pairing.
- When non-combustible brick or aluminium cladding was paired with a PIR or PF insulation the overall HRR was found to be comparatively low (< 5.5 kW).
- Changes in cavity widths between 25 and 100 mm were found to have a small influence on the fire performance for the tested assemblies. Cavity widths greater than 100 mm were found to *reduce* the fire growth rate and fire size.

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7. References

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Appendix A – Testing notes

The manner in which the data is presented above is intended to be useful in terms of synthesis or analysis. However, it inevitably cannot present every test in full detail. There were some cases where it may be useful for readers to appreciate particular details of circumstances or events within tests. These are highlighted in Table A.1.

Table A.1. Summary of testing notes.

Test reference	
No. 54	During this test, the extraction system in the laboratory was unable to capture all the combustion products. As a result, the heat release rate data for this experiment is likely to under-estimate the peak fire size (and total energy released). Data from this test was therefore not included within the averages or metrics described in the body of this report. Nevertheless the test was allowed to run for the full 30 minutes and other data was captured effectively. Therefore, for completeness, this test is included within the dataset. In anticipation of the large fire size for subsequent ACM PE tests the extract rate in the laboratory was increased and therefore all the products of combustion were captured.
No. 47, 89	Experiment 47 (ACM A2 cladding with PF insulation) and experiment 89 (Brick cladding with PF insulation) were observed to begin smouldering towards the end of the 30-minute test. For interest, these tests were continued after the 30 minutes had elapsed to observe this behaviour (although for consistency, only data up to 30 minutes is included within the dataset). It was observed that the smouldering eventually transitioned to flaming and after approximately 50 minutes both experiments had reached a peak fire size (between 25 and 42 kW). Flaming and smouldering continued until much of the PF insulation panels had been consumed.