Large scale exposure of fires to facade - Initial testing of proposed European method

Johan Sjöström, Johan Anderson, Fredrik Kahl, Lars Boström, Emil Hallberg

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Abstract

Large scale exposure of fires to facade - Initial testing of proposed European method

This report describes a series of tests of the new proposed method for assessing the performance of façades when exposed to flashover fires. The tests consider the large fire exposure and consists of the 8.5 meter high incombustible walls placed in a 90° angle towards each other. The report assesses reproducibility and the effect of moisture content, stick size, wind and depth of the combustion chamber.

The data from the report will be publicly available at the project website for further use and scrutiny. https://www.ri.se/en/what-we-do/projects/finalisation-of-the-european-approach-to-assess-the-fire-performance-of-facades

Key words: Facades; fires; testing; assessment; Standardisation; wood cribs

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Summary

This report describes the results of a test series with the proposed European method for assessing the fire performance of façade systems. In this series, a completely inert façade was used, and the study investigated repeatability, reproducibility and the effect of wood cribs moisture content, wood stick size, external wind and depth of the combustion chamber.

The method originates from the British BS8414 and still resembles that method with regards to heat source and dimensions. However, the exposure, as measured by water cooled heat flux meters (HFM) 1 m above the combustion chamber, show that the total heat flux to the cool HFM is larger than specified by the BS8414 standard. Similar results were shown also for previous wood crib tests in this project.

The thermal exposure to the façade is largest at 1.5 m above the combustion chamber top and thereafter decreases with height. Small thermocouples exhibit a higher temperature than plate thermometers and the thermal impact is probably dominated by convective heat transfer.

The results, following the results of wood crib testing done previously in the same project (Efectis, 2021), show that there is an effect of moisture content of the sticks but that within the tolerances of the proposed method, this effect is marginal. Also, the stick dimensions affect the results, mostly in terms of stability of the cribs, which in turn affects the duration of the high thermal exposure to the façade. The height of the cribs is shown to make a difference for the tests and a discussion is needed on weather a constant height or a constant weight of the crib is the best way forward. The combustion chamber depth was shown also to have only a marginal effect and the chamber depth is therefore suggested to be increased from the previous suggestion in order to protect the crib.

The largest effect was found when external wind was applied to the façade. Fans, producing windspeeds of at the most 2.5 m/s measured one meter from the centre of the façade and 1 m above the opening significantly reduced flame height, heat flux to the HFM in the façade as well as the temperatures measured by small thermocouples and plate thermometers along the façade surface. The reduction in thermal impact was achieved without any reduction in mass loss rate of the wood crib (the mass loss rate rather increased instead). What normal wind speed the measured wind speed in front of the façade surface corresponds to is yet to be investigated.
1 Background

The report describes the initial testing activities of the calibration exercise using the large fire exposure as a part of the European project “Finalization of the European approach to assess the fire performance of facades – Project: SI2.825082”. The project was initiated in the spring of 2020 with a theoretical round robin using the alternative method developed in a previous project called “Development of a European approach to assess the fire performance of facades”. The round robin resulted in more comprehensible assessment method which benefitted from input of stakeholders and other liaisons. The assessment method described the dimensions of the test rig with combustion chamber including the fire source. A separate experimental program for the wood cribs used as fire source took place during 2021 where further limitations in possible variability stemming from the properties of the wood cribs was introduced. In this test series the combustion chamber and a shortened façade was included which enables comparisons with the current stage where the full façade rig is used. In the current stage the repeatability and reproducibility of the method is studied such that more knowledge on variations in the heat exposure to façade is accumulated. The heat exposure to the test specimen depends on many factors such as fuel type, ventilation conditions (forced or natural ventilation) in the combustion chamber, ventilation conditions in the fire test facility room or environment, and position of fire load in relation to the surface of the test specimen.

2 Experimental

2.1 Geometry

The main face of the façade was 8.5 m high and 3.2 m wide. A secondary face of same height and 1.5 m width was placed in a 90° angle on the right side (Figure 1). The combustion chamber was built of lightweight concrete (nominal density 525 kg/m³) blocks (600 x 200 x 150 mm LxWxB). The rest of the façade above the combustion chamber was built in 100 mm thick lightweight concrete (nominal density 575 kg/m³) blocks (2200 x 600 x 100 mm LxWxB). The only exception from the lightweight concrete was a concrete beam of normal density (2400 kg/m³) previously exposed to flames from in many fire tests. The area covered by the concrete beam was on the main face from 300 to 600 mm above the opening of the combustion chamber. The back side of the façade was supported by a steel frame, placed on the concrete beam, in turn supported two steel beams on each side of the combustion chamber (Figure 1).
Figure 1. (Left) Face of the façade construction. The concrete beam of normal density is shown as the grey field just over the opening of the combustion chamber. (Right) Backside of the construction with the supporting steel structure.

The combustion chamber was internally 2200 mm high, 2400 mm wide and 1300 mm deep. However, a 150 mm deep and 200 mm high downstand reduced the actual opening height to 2000 mm. Also, walls on each side of the opening reduced the width to 2000 mm as well (Figure 2).
Figure 2. Sketches of the combustion chamber dimensions vertical (Left) and horizontal (Right). cross-sections. All numbers refer to distances in mm.

The floor of the combustion chamber was located 500 mm above the floor of the lab. Under the combustion chamber floor, 4 load cells supported a steel section each, penetrating the floor (Figure 3 – left). A 400 mm high steel structure on which the wood crib was built, was thereafter mounted on the section such that the whole structure and crib was completely supported by the load cells (Figure 3 – right). The floor between the wood crib and the supporting steel was a solid plate of 40 mm thick incombustible board. In all test but the initial “test 0” the internal walls, ceiling and floor of the combustion chamber were cladded with 50 mm thick ceramic insulation of 125 kg/m³, as shown in Figure 3 – right.

The cribs were ignited by a gas lighter igniting 14 heptane-soaked fibre boards (1 m long, 15 x 20 mm section) inserted in the 14 voids above the first layer of sticks.
2.2 Instrumentation

The load cells under the combustion chamber floor were 1 kN compression load cells such that the resolution for the mass loss of the crib was maximised. Additionally, the main façade was instrumented by plate thermometers (PT) in a vertical line central above the combustion chamber opening at 0, 1000, 2500, 5000 and 6000 mm above the chamber opening. Offset from this vertical line, one PT was located in the centre of the fictitious window described in Boström et al. (2021) (Figure 4). All PT were mounted with a 10-20 mm gap between the backside of the PT and the façade surface.

Along with temperatures recorded by PT, 1 mm thick shielded Inconel thermocouples (TC) were placed with 500 mm distance in a line vertically over the centre of the combustion chamber and in two horizontal lines across both the main and face and the secondary face at 2500 and 5000 mm above the chamber opening (Figure 4).

In front of the opening a 50 kW/m² water cooled heat flux meter (Schmidt-Boelter gauge) was placed alongside a special plate thermometer designed for measuring incident radiation from fires (Sjöström et al. 2015) 1.3 m in front of the façade at mid height of the combustion chamber opening (Figure 5). A 200 kW/m² Gardon gauge was installed next to the PT and TC placed 1000 mm centrally above the combustion chamber opening. The measuring point of the gauge was placed flush with the façade surface.
Figure 4. Placement of thermocouples (TC) and plate thermometers (PT) on the main façade (left) and wing (right). The light grey area is the combustion chamber opening.
Figure 5. Schmidt-Boelter gauge and special PT placed 1.3 m in front of the façade at mid height of the combustion chamber opening. The photo is from test 0 in which the combustion chamber interior walls was not insulated.

Flame heights were measured using the video recording of the test. Each frame is transformed into a grey image and the boundary of the flame is defined out of an intensity of the grey scale which thereafter defines flame regions in a binary image. The largest area of any flame region is chosen to represent the flame. Thus, a small flame detached from the main flame is not considered being a part of the flame. A rectangle fitting the largest flame region defines the width and height of the flame. Assuming a flat projection (constant pixel/distance ratio) the number of pixels defining the rectangle also defines the flame size. More information on this algorithm can be found in Sjöström et al. (2021) and a reference example is shown in the appendix (Figure 79).

In the last test different materials were placed on the floor in front of the combustion chamber to investigate the potential of ignition of falling façade parts from the wood crib itself. The materials were (i) paper, (ii) wood, (iii) EPS, (iv) rubber and (v) thin PE plastics. The materials, a few cm in diameter, were placed at 0.5 and 1.0 m distance from the façade surface (Figure 6).
Figure 6. Combustible material placed 0.5 and 1.0 m in front of the combustion chamber in test 6.

2.3 Tests

One initial test, labelled test 0, was conducted to remove moisture and test the setup along with six other tests.

The first three actual tests (tests 1-3) were three replica tests with small variations in crib weight, moisture, dimensions (47.6 ± 0.7 mm) and with some variations in nailing procedure. A less deep combustion chamber was tested in test 4 with the same dimensions as in Previous wood crib tests (Efectis, 2021). A forced wind was applied in test 5 and finally, for test 6, a somewhat dryer wood crib with a smaller section size (45 ± 1.0 mm) was tested.

Details of the cribs used in the different tests are shown in Table 1 and other differences between tests in Table 2. For test 4 the load cells under the platform were not used since the position of the platform was shifted.

Table 1. Properties of the cribs in the different tests

<table>
<thead>
<tr>
<th>Test number</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section size (mm)</td>
<td>47.6 ± 0.5</td>
<td>47.7 ± 0.5</td>
<td>47.6 ± 0.7</td>
<td>47.5 ± 0.7</td>
<td>47.7 ± 0.7</td>
<td>47.5 ± 0.8</td>
<td>44.9 ± 0.8</td>
</tr>
<tr>
<td>Layers</td>
<td>24</td>
<td>23</td>
<td>25</td>
<td>24</td>
<td>23</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>Crib height (cm)</td>
<td>114</td>
<td>110</td>
<td>119</td>
<td>114</td>
<td>110</td>
<td>114</td>
<td>117</td>
</tr>
<tr>
<td>Density (#sticks probed)</td>
<td>469</td>
<td>454</td>
<td>421</td>
<td>423</td>
<td>442</td>
<td>436</td>
<td>448</td>
</tr>
<tr>
<td>Total mass (kg) probed</td>
<td>382</td>
<td>355</td>
<td>358</td>
<td>343</td>
<td>347</td>
<td>351</td>
<td>353</td>
</tr>
<tr>
<td>Total mass (kg)</td>
<td>-</td>
<td>-</td>
<td>352</td>
<td>340</td>
<td>N.A.</td>
<td>-</td>
<td>349</td>
</tr>
<tr>
<td>Load cells</td>
<td>-</td>
<td>-</td>
<td>352</td>
<td>340</td>
<td>N.A.</td>
<td>-</td>
<td>349</td>
</tr>
<tr>
<td>MC (%) #sticks probed</td>
<td>14.0</td>
<td>13.84</td>
<td>13.12</td>
<td>12.19</td>
<td>13.44</td>
<td>11.35</td>
<td>12.94</td>
</tr>
<tr>
<td>Nailing</td>
<td>2nd layer, 3rd joint</td>
<td>2nd layer, 3rd joint</td>
<td>all layers, 3rd joint</td>
<td>all layers, 3rd joint</td>
<td>all layers, 3rd joint</td>
<td>all layers, 3rd joint</td>
<td>all layers, 3rd joint</td>
</tr>
</tbody>
</table>
Figure 7. Nailing the wood cribs.

Table 2. Variations within the different tests.

<table>
<thead>
<tr>
<th>Test number</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 0</td>
<td>No insulation in the combustion chamber, façade previously not exposed to fire</td>
</tr>
<tr>
<td>Test 1</td>
<td>Standard reproducibility tests</td>
</tr>
<tr>
<td>Test 2</td>
<td>Combustion chamber rebuilt to achieve less depth (from 1.3 m to 1 m)</td>
</tr>
<tr>
<td>Test 3</td>
<td>No load cells were used</td>
</tr>
<tr>
<td>Test 4</td>
<td>Testing with forced wind on the façade</td>
</tr>
<tr>
<td>Test 5</td>
<td>Smaller stick section (45 mm instead of 47.6)</td>
</tr>
</tbody>
</table>

The applied wind in test 5 was achieved using three large fans positioned 10 to 15 m from the façade at different heights. The wind speed was measured at three positions relative the façade surface. Position 1 and 2 were at the far end on the main façade, 3.2 m from the corner and at a distance of 0.5 and 1 m from the main façade surface, respectively. Position 3 was measured centrally on the main façade and 1 m from the façade surface. All positions were measured at five different heights (between -0.5 and 5 m) relative the opening top (Figure 8).
Figure 8. Wind speeds measured prior to test 5. The positions (pos) are given relative the façade surfaces to the right. The arrows indicate the wind direction relative the façade shown to the right.
3 Results

3.1 Overview

Figure 9. snapshots from tests 1-4.
All results from the tests are given in the appendix. In this section we give an overview of the results and highlight a few of the results. Photos from all the six main tests are shown in Figure 9 and Figure 10.

The temperatures (shown as averages during 5 - 20 minutes after ignition) of the TC and PT above the combustion chamber as function of height show the most severe conditions at about 1.5 m above the combustion chamber (Figure 11). For most of the tests the TC temperature is 800 – 900 °C just at the opening, reaching a maximum about 1000 °C at 1.5 m height and monotonically decreases with additionally increasing height to 300 – 350 °C at 6 m above the opening top. 1 and 2.5 m above the opening the PTs show about 150 °C lower temperatures than the TCs while the discrepancy between the two temperature probes decrease to about 75 °C at 5 and 6 m above the opening, this is discussed below.

The typical shape of the flame as it ejects from the opening moving upwards and, after a meter or so, retreats back to the façade explains the height dependence of the flame (Figure 12, left).

The materials placed in front of the combustion chamber in test 6 were all affected by the heat. The paper at 0.5 m distance burnt already after 4 minutes but at 1 m distance it only shifted into brown colour. The thin PE-plastics shrunk to a small lump without smoking or flaming. Timber at 0.5 and 1.0, discolorised without starting to flame. Rubber started flaming at 0.5 m distance and exhibited significant smoke at 1.0 m. EPS plastics burnt at both 0.5 and 1.0 m distance.
Figure 11. TC (solid lines) and PT (□) temperature variations with heights for all tests. The temperatures are averaged over 5 – 20 minutes after ignition.

Generally, the PT temperatures are lower than the TC temperatures, suggesting that the flame is optically thin and convective heat transfer dominates the thermal impact to the façade.

Figure 12. Side view of the ejected flame at 22:00 in test 2 (left) and 4:30 in test 4 (right).
Table 3. Some key results from the tests.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Test 5</th>
<th>Test 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame height (m) (^1)</td>
<td>3.0</td>
<td>3.4</td>
<td>3.5</td>
<td>3.8</td>
<td>2.6</td>
<td>-</td>
</tr>
<tr>
<td>First crib parts on the floor (min) (^2)</td>
<td>23:30</td>
<td>24:20</td>
<td>22:20</td>
<td>22:00</td>
<td>23:25</td>
<td>20:05</td>
</tr>
<tr>
<td>First crib collapse (min) (^2)</td>
<td>21:00</td>
<td>19:40</td>
<td>19:45</td>
<td>19:40</td>
<td>22:00</td>
<td>19.00</td>
</tr>
<tr>
<td>Average mass loss rate (kg/s) (^1)</td>
<td>-0.204</td>
<td>-0.206</td>
<td>-0.202</td>
<td>(-)</td>
<td>-0.213</td>
<td>-0.220</td>
</tr>
<tr>
<td>Max TC at 2.5 m above opening (°C)</td>
<td>906</td>
<td>956</td>
<td>936</td>
<td>965</td>
<td>616</td>
<td>915</td>
</tr>
<tr>
<td>Max TC at 5 m above opening (°C)</td>
<td>479</td>
<td>509</td>
<td>503</td>
<td>556</td>
<td>284</td>
<td>498</td>
</tr>
<tr>
<td>Max PT temp at 2.5 m (°C)</td>
<td>723</td>
<td>784</td>
<td>768</td>
<td>790</td>
<td>516</td>
<td>760</td>
</tr>
<tr>
<td>Max PT temp at 5 m (°C)</td>
<td>359</td>
<td>399</td>
<td>382</td>
<td>417</td>
<td>178</td>
<td>369</td>
</tr>
<tr>
<td>Av. heat flux to HFM façade (kW/m(^2)) (^1)</td>
<td>116</td>
<td>116</td>
<td>115</td>
<td>106</td>
<td>67</td>
<td>94</td>
</tr>
<tr>
<td>Max heat flux to HFM façade (kW/m(^2))</td>
<td>144</td>
<td>143</td>
<td>133</td>
<td>123</td>
<td>85</td>
<td>110</td>
</tr>
</tbody>
</table>

\(^1\)Averaged between 5 and 20 minutes from ignition.

\(^2\)From time after ignition.

Figure 13. Total heat flux to Schmidt-Boelter gauge centred 1000 mm above the opening top, flush to the façade surface.
3.2 Comparative analysis of results

In this section some aspects of the test rig are discussed separately.

3.2.1 Repeatability

Tests 1-3 differ only a little between them. The cribs were built according to the procedure in Boström et al. (2021) and with no intention to vary the parameters. The moisture content is largest in test 1 and lowest in test 3. However, since the density of the sticks in test 1 was somewhat higher the number of layers is highest in test 2 (25), followed by test 3 (24) and test 1 (23), Table 4.

![Figure 14. Mass and mass loss rate from tests 1-3.](image)

The mass loss rates, as averages between 5 and 20 minutes, differ only 1.9 % between the tests (Figure 14).

Table 4. Properties of the cribs in the different reproducibility tests

<table>
<thead>
<tr>
<th>Test number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stick layers</td>
<td>23</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Crib height (cm)</td>
<td>110</td>
<td>119</td>
<td>114</td>
</tr>
<tr>
<td>Density (kg/m$^3$)</td>
<td>454</td>
<td>421</td>
<td>423</td>
</tr>
<tr>
<td>Total mass (kg)</td>
<td>355</td>
<td>358</td>
<td>343</td>
</tr>
<tr>
<td>MC (%)</td>
<td>13.8</td>
<td>13.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Nailing</td>
<td>2$^{nd}$ layer, 3$^{rd}$ joint</td>
<td>2$^{nd}$ layer, 3$^{rd}$ joint</td>
<td>all layers, 2$^{nd}$ joint</td>
</tr>
<tr>
<td>Average MLR (kg/s) 5 – 20 min</td>
<td>-0.204</td>
<td>-0.206</td>
<td>-0.202</td>
</tr>
<tr>
<td>Max TC temp @5000 mm (30 s average)</td>
<td>479</td>
<td>509</td>
<td>503</td>
</tr>
<tr>
<td>Max $q''$ to Schmidt-Boelter gauge in façade (kW/m$^2$, 30 s average)</td>
<td>144</td>
<td>143</td>
<td>133</td>
</tr>
</tbody>
</table>

The temperature difference of the TCs between the tests (1-3) are within 65 °C and 80 °C of each other at 5000 and 2500 mm height, respectively, and the height profile follow the same shape (Figure 15). Test 1 displays the lower temperatures whereas test 2 and 3 differ less than 20 °C, both for TC and PT gauges. Test 3 has the lowest moisture content
of the crib but test 2 has one more layer of sticks. Test 1 has both the highest moisture content and lowest crib height, both of which are unbenefficial for high temperatures.

Figure 15. TC (lines) and PT temperatures (average between 15 and 20 minutes) at different height above the opening for tests 1-3.

Test 1 also show lower flame heights, the total variation between the tests are 14 % of their average (Figure 16).
3.2.2 Wind

Of the varied parameters wind had the largest influence on the temperatures measured on the façade. Despite having the lowest moisture content of the wood crib, the temperatures are considerably lower compared to the tests without forced ventilation. At 2500 mm and 5000 mm height the TC temperatures are 371 and 277 °C lower in test 5 compared to test 3 (Figure 11). The flame is considerably lower when forced wind is applied compared to e.g. test 3 (Figure 17). Average height between 5 and 20 minutes is 2.6 m for test 5 compared to 3.5 m for test 3.

![Flame height, Tests 3 & 5](image)

**Figure 17.** Flame heights of test 5 (forced wind) and test 3.

The temperature of the wing is more homogeneous in test 5 (wind) compared to the ones done without external wind as evident from the full data in Appendix (e.g. Figure 57).

3.2.3 Wood moisture content

The procedure according to Boström et al. (2021) when constructing the crib defines the tolerance for moisture content is 11 ± 2 %. The variation of moisture content in the tests performed here is 1.65 %-units, ignoring test 5 where wind is included. There seems to be very little influence on the temperatures more than the indirect effect of moisture on the density, which in turn influences the height of the crib. Comparing test 2 and 3, which are very similar except for a 1 %-unit higher moisture content and one more layer in the crib in test 2 compared to test 3. Despite the higher moisture content test 2 still exhibits small but consistently higher TC and PT temperatures due to the extra stick layer.

3.2.4 Combustion chamber depth

The depth of the combustion chamber has implications on protecting the crib from outer disturbances and the velocity of the flame as it is ejected from the chamber. Test 4 (1 m

---

1 The moisture content difference between test 5 (wind) and test 1 is 2.5 %-units.
deep chamber) and test 1 (1.3 m deep chamber) are much alike (varying 2.7 % in density, 0.4 %-units in moisture content and with same height). However, test 4 displays the hottest temperature profile with 70 – 80 °C higher TC temperatures. (Figure 11). The largest effect is just above the opening where the deeper combustion chamber ejects the flame further from the façade during the first meter above the chamber (c.f. Figure 12).

Test 4 also has the highest flame height, just above that of test 3 (Figure 18).

![Figure 18. Flame heights of test 1, 3 and 4 (all tests are scaled such that combustion chamber flashover occurs at t = 0 min).](image)

4 Final remarks

4.1 Parametric considerations

The wood stick dimension tolerances (44 – 50 mm sections) are defined according to Boström et al (2021). A smaller section would increase the surface to volume ratio and thereby it is anticipated to increase the thermal impact to the façade through an increased burning rate. However, the change in section size to 44.9 mm in test 6 from 47.6 mm (6 % reduction) does not seem to have a major impact. Test 6 and 2 are similar in terms of moisture content but the decreased section size of test 6 is easily counterbalanced by the only 2 cm additional height of the crib in test 2 as well as the 6 % higher density, shown by the 13 – 30 °C higher TC temperatures in test 2 compared to test 6.

Cribs built from smaller sections collapsed earlier compared to the 47.6 mm sticks and we can also detect an earlier collapse compared to typical times from the BS 8414 method. A part of this can probably be attributed to the size of studs in the British method.
(50 mm) but also that spruce (these tests) has a higher tendency to crack and burst into smaller sections than pine do (BS 8414).

Boström et al. (2021) specifies a total range of 4 %-units for variations in moisture content. It is shown here that 1.5 %-units have a smaller impact on the thermal exposure to the façade compared to many other parameters such as the height of the wood crib and in particular the external wind speed.

The total variation in density within this test series is only 7.5 % of the average density of 437 kg/m³. However, the previous test report from this project showed that density plays mostly the role of delaying the high impact period and prolonging the time for decay, thus shifting the whole exposure to later times without significantly affecting the magnitude (Efectis, 2021).

The procedure of building the crib as defined in Boström et al. (2021) aims to achieve a crib with a total weight within a certain narrow range. Variations in total weight are suggested by the results here to be less important than the total height of the crib, even though all these variations are small. All three tests aimed at investigating repeatability (tests 1 - 3) lie within an acceptable range in measured temperatures and heat fluxes on the façade.

4.2 Collapse and falling parts

There have been discussions on whether a lift-up of the combustion chamber is needed in order to be able to assess falling parts. The worry has been that falling parts not burning upon descent would ignite by the radiant heat from the wood crib and thereby be impossible to assess after the test. However, these tests show that considerable fall-out of the wood crib itself happened in all tests before 22 minutes after ignition and any material fallen from a façade would nevertheless be affected by burning charcoal, regardless of any lift-up.

It is instead more suitable to assess the falling parts as they fall by visual observations and by video monitoring.

4.3 Height of the combustion chamber

If there is no need to protect falling parts from the radiant heat of the burning wood crib, it is therefore neither important to keep the first 500 mm of the façade (see Figure 4 and Figure 5 for reference). Instead, the combustion chamber floor can be situated right on the floor as it is done in the BS 8414 method. While that space was needed in these tests for performing the load cells measurements, there is no need for such extra void in a real test setup.

If the total height above the combustion chamber was also reduced by 500 mm (leaving 500 mm above the highest anticipated assessment point), the total height of the test rig would be reduced to 7.5 meters instead of the 8.5 meters used in this series. The reduced height would make the test significantly cheaper and thereby increase the incitement for testing façade systems.
4.4 Discrepancy between oxygen consumption calorimetry and mass loss rates

Calculating the heat release rate (HRR) from the mass loss rate is a popular method when oxygen consumption calorimetry (OCC) is not at hand. Assuming a fixed release of energy per unit mass of pyrolyzed gasses enables the calculation of heat release rate from a specimen. The effective heat of combustion, $\Delta H_c$, of spruce timber is however contested and varies in the literature between 17.5 MJ/kg ± 2.5 MJ/kg (Bartlett et al., 2019), but values as low as 12 MJ/kg are also found (Parker, 1988). Running the analysis for the five tests with measured mass loss rates shows that the HRR (as for the MLR) is highly uniform between the tests. However, only the very lowest value of $\Delta H_c$ (12 kJ/kg) will to some extent match the value measured by the oxygen consumption calorimetry.

The mass loss rates measured here are in line with previous tests done at Efectis within this project (Efectis, 2021) but in those test the oxygen consumption calorimetry of similar cribs (solid plate, spruce) gave just under 3 MW and a mass loss rate of -0.18 kg/s. The two methods fit nicely assuming a $\Delta H_c = 16.4$ kJ/kg.

![Figure 19](image_url)

The discrepancy between the two methods of measurement is not known but it is assumed that all fire emissions were not collected by the hood in the lab (situated 10 m above the fuel source). Since the hot gases are virtually transparent it is difficult to decide using visual observations.

5 References


6 Appendix A – All results

6.1 Test 1

Figure 20. Time evolution of thermocouples centred above the opening. Numbers refer to distance above combustion chamber opening.

Figure 21. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 22. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 23. Time evolution of PT above the opening.
Figure 24. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 25. Mass from the load cells supporting the crib (Right axis, red) and mass loss rate of the same (right axis, black).
Figure 26. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)

Figure 27. Temperatures of TC (line) and PT (□) at different heights directly above the opening.
Figure 28. Flame heights. Ignition starts at $t = 0$ min.
6.2 Test 2

Figure 29. Time evolution of thermocouples centred above the opening.

Figure 30. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 31. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 32. Time evolution of PT above the opening.
Figure 33. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 34. Mass from the load cells supporting the crib (Right axis, red) and mass loss rate of the same (right axis, black).
Figure 35. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)

Figure 36. Temperatures of TC (line) and PT (□) at different heights directly above the opening.
Figure 37. Flame heights. Ignition starts at $t = 0$ min.
6.3 Test 3

Figure 38. Time evolution of thermocouples centred above the opening.

Figure 39. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 40. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 41. Time evolution of PT above the opening.
Figure 42. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 43. Mass from the load cells supporting the crib (Right axis, red) and mass loss rate of the same (right axis, black).
Figure 44. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)
Figure 45. Temperatures of TC (line) and PT (□) at different heights directly above the opening.

Figure 46. Flame heights. Ignition starts at t = 0 min.
6.4 Test 4

Figure 47. Time evolution of thermocouples centred above the opening.

Figure 48. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 49. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 50. Time evolution of PT above the opening.
Figure 51. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).
Figure 52. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)

Figure 53. Temperatures of TC (line) and PT (∇) at different heights directly above the opening.
Figure 54. Flame heights. Ignition starts at $t = 0$ min.
6.5 Test 5

Figure 55. Time evolution of thermocouples centred above the opening.

Figure 56. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 57. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 58. Time evolution of PT above the opening.
Figure 59. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 60. Mass from the load cells supporting the crib (Right axis, red) and mass loss rate of the same (right axis, black).
Figure 61. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)
Figure 62. Temperatures of TC (line) and PT (□) at different heights directly above the opening.

Figure 63. Flame heights. Ignition starts at $t = 0$ min.
6.6 Test 6

Figure 64. Time evolution of thermocouples centred above the opening.

Figure 65. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance (mm) from the corner.
Figure 66. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 67. Time evolution of PT above the opening.
Figure 68. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 69. Mass from the load cells supporting the crib (Right axis, red) and mass loss rate of the same (right axis, black).
Figure 70. Total HRR from the oxygen consumption calorimeter (OCC). (Note that incomplete collection of the fire gases is suspected, see section 4.4.)

Figure 71. Temperatures of TC (line) and PT (□) at different heights directly above the opening.
6.7 Test 0

Figure 72. Time evolution of thermocouples centred above the opening.

Figure 73. Time evolution of horizontal thermocouples at 2500 (solid lines) and 5000 mm (dotted lines) above the opening. Numbers refer to distance in mm from the corner.
Figure 74. Time evolution of thermocouples at 5 (solid lines) and 7.5 m (dotted lines) height from ground. 2nd number refers to distance in mm from the corner.

Figure 75. Time evolution of PT above the opening.
Figure 76. Total heat flux to the HFM in the façade, 1000 m above opening (red) and in front of the combustion chamber (half height) at 1.3 m distance (black). Also shown is incident heat flux calculated from PT next to HFM in front of the crib (blue).

Figure 77. Total HRR from the oxygen calorimeter
Figure 78. Temperatures of TC (line) and PT (□) at different heights directly above the opening.
6.8 Photos

Figure 79. Colour, gray scale and binary images of a flame snapshot to define flame height.
Figure 80. Very end of test 4.

Figure 81. Wood crib with the 14 fibre boards, soaked in heptane, used for ignition.
Figure 82. During construction of the inert façade.
Figure 83. During construction of the inert façade.
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