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# Experimental comparisons in façade fire testing considering SP Fire 105 and the BS 8414-1

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## Summary

A comparison between full-scale façade fire tests where SP Fire 105 and BS 8414-1 were used regarding repeatability and the use of modeling to discern changes in the setups is presented. Two test series according to BS 8414-1 were repeated outside using the same façade systems on 2 different days, whereas for the SP Fire 105 a set of common façade systems in Sweden were tested indoors. In particular, the results show that the wind around the test setup may have a significant impact on the tests and that the heat exposure to the façade surface will depend on the thickness of the test specimen where an increased temperature in front of the façade, and a decreased temperature on the façade 2.1 m above the fire room, is observed experimentally. The heat exposure to the test specimen varies to a more limited extent when an uncontrollable free burning fire source is used (in this study heptane and wood, respectively) and that this variation increases when wind is present.

**KEYWORDS**

BS 8414-1, facade test, fire, repeatability, SP Fire 105

## 1 | INTRODUCTION

Fire spreading from floor to floor via external walls is an important component to consider when assessing fire safety of buildings.[1] Fire hazards of this type have been investigated for a long time,[1-12] and a number of test methods have been proposed and implemented in order to evaluate different wall claddings, insulations, and geometrical considerations.[1,5-12] Theoretical modeling such as analytical estimates of prevention of fire spread caused by a hot upward current[2] and more recently numerical studies introduced of the SP Fire 105 test rig using the CFD code SOFIE[3] have been performed. However, there are different possible ways of fire spread via external wall such as, eg, inadequate fire stop in the gap between floor slab and exterior wall allowing for flames and hot gases into the next compartment; deflection or distortion of metallic façade materials, eg, aluminum, leading to deterioration of the fire safety; inadequate fire stopping around service penetrations, windows, but the focus in this article is the spread through an external fire plume.[1] In real fires, important factors influencing the size and shape of this external fire plume are the original fire source inside the room, the fuel excess factor, and the geometry. The situation today is that a large number of different tests are used for verification and classification of façade systems, ranging from small scale tests to full scale tests.[6] Because each country has their own building regulation, there is a large spread in the requirements and procedures on how to present the performance of the façade system.[6-9] The fire exposure conditions represent an external fire source or a fully developed fire in a room, venting through an opening such as a window aperture that exposes the cladding to the effects of external flames.

There are many factors that can influence on the repeatability[13] of a test method, and in façade testing the environment is of great importance. In this work, experimental tests using BS8414-1 and SP Fire 105 are performed and compared. The BS 8414-1 tests are repeated tests with the same materials on 2 different days with similar weather conditions, while the SP Fire 105 are tests of a number of different commonly used façade systems. The experimental results show that the fire exposure to the façade varies in both BS 8414-1[14] and SP Fire 105[15] depending on environmental and geometrical factors. Both methods define an amount of fuel to be used: in BS 8414-1, a volume of wood and in SP Fire 105 a volume of heptane, and the geometry of the combustion chamber. It is thus not possible to regulate the heat exposure to the façade surface in real time during the test, and it

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may be different from test to test due to factors such as air movements around the combustion chamber and geometry of the test specimens; however, a varying fire exposure due to the latter might or might not be a problem; it depends on where the boundary of the room fire is set. The Swedish test method was originally developed in the middle of the 1980s as a part of a large study including burning of 14 façades with a fully developed room fire as a heat source.[10,12] The results of this test series made it possible to optimize the fire exposure in the SP Fire 105 test method to correspond to typical room fire. During the tests, approximately 50% of the fuel was estimated burning outside the chamber. This factor is dependent on the geometry of the enclosure and on fuel parameters such as composition and geometry.

In both test methods, post-test examination is required where, eg, the extent of flame spread over the surface and flame spread or damage within the specimen should be noted. Also, to which extent the external cladding burnt away or was detached, however the requirement of falling off parts and burning droplets are only included in SP Fire 105.

The paper is organized in the following way. First is the qualitative modeling of the geometrical effect on the fire plume discussed which is then verified in the experimental part. The repeated tests performed according to the BS 8414-1 test standard are presented and analyzed using the same façade systems tested on 2 different days. This is followed by a similar analysis of common façade systems tested according to the SP Fire 105 standard. In all tests, additional plate thermometers (PT) were introduced to characterize the fire source and the fire exposure on the façade, which gives results that are also comparable between the methods. At the end of the paper is a conclusion and discussion section where the repeatability and large variations that are present in tests are explored.

## 2 | FIRE TESTS

### 2.1 | BS 8414-1 tests (Zagreb tests)

In BS 8414-1, the test specimen extends 6 m above the combustion chamber and is 2.6 m wide with a return wall (wing) of the same height and 1.5 m wide. The square opening of the combustion chamber has side length of 2 m, and the fire source is a wood crib with a nominal total fire load of 4500 MJ over 30 minutes at a peak rate of 3 ± 0.5 MW (Figures 1 and 3). The prescribed measurements defined in the standard[9] are performed at 2 heights from the top of the combustion chamber, at 2.5 and 5 m. Type K (Chromel/Alumel) mineral-insulated 1.5-mm (nominal) diameter thermocouples with insulated junctions were used for standard temperature measurements, based on the relevant BS 8414-1 standard. Additional thermocouples (1.0, 1.5, and 3.0 mm in nominal diameter, respectively) and PT were used during the tests to measure the temperatures at different heights from the combustion chamber. Additional external thermocouples (1.0 and 3.0 mm nominal diameter thermocouples as well as PT) were placed at 1.25, 2.50, 3.75 and 5.00 m above the combustion chamber positioned in the middle of the main face of the specimen. Plate thermometers were pointing outwards from the façade at all heights mentioned earlier, while they were pointing towards fire source at the height of 1.25 and 3.75 m above the combustion chamber. Additional internal thermocouples (1.5-mm nominal diameter thermocouples) were placed 0.60, 1.00, 1.70, and 3.00 m above the combustion chamber in the middle of the main face as well as 0.15 m from the joint on both main face and the specimen's wing, respectively.

Two series of tests have been performed outdoors in Zagreb, Croatia, one in March 2014 (referred to as Test A) and one in May 2014 (referred to as Test B). The tests were made in accordance with BS 8414-1:2002.[14] In each test, 3 façade rigs were used simultaneously with different test specimens, ie, 3 different façade systems shown Figure 1. The 3 façades were prepared with different types of external thermal insulation composite systems.[16] The fire exposure conditions represent an external fire source or a fully developed fire in a room,[14] venting through an opening such as a window aperture that exposes the cladding to the effects external flames. The façades as shown in Figure 1 consist of noncombustible mineral wool insulation, EPS insulation, and fire stops at different heights of rock-wool insulation, an of EPS insulation as summarized in Table 1. All 3 walls had a 5-mm organic rendering on the surface and classified for the reaction to fire as B-s2,d0 or better.

The 2 tests were exactly the same, except the climate conditions because the tests were carried out outdoors. In the first test, the temperature was within the range of 11.2°C to 12.3°C, and the wind speed

**TABLE 1** Material under the organic rendering in BS 8414-1 tests

| | |
|---|---|
| Wall 1 | Noncombustible mineral wool insulation |
| Wall 2 | EPS insulation and fire stops at different heights of rock-wool insulation |
| Wall 3 | EPS insulation. |



**FIGURE 1** The specimens for BS 8414-1 tests (Zagreb tests) [Colour figure can be viewed at wileyonlinelibrary.com]

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varied between 1.8 and 5.4 m/s. The wind was directed in north to north-west direction, center-left in Figure 1. In the second test, the temperature was within the range of 20.5°C to 22.2°C, and the wind speed varied between 2.2 and 4.5 m/s. During the tests, the weight of the fuel was measured by load cells. The initial weight of each wood crib is given in Table 2. It can be noted that the initial weight differs considerably because the standard only prescribes the volume of wood to be used and it does not consider the large difference of density of wood. In Figure 2 is the fuel consumption during the test shown. The fuel consumption has been calculated as the time derivative of the fuel weight throughout the test. The data indicate that the fuel consumption was much faster during the test in Test A due to different conditions during the test. There are a number of factors that may have an impact on the burning rate; among them are that the wind speed was higher, different moisture content, and different initial weight of the wood. Note that, the moisture content was decreased from 15% to 16% to 10% to 11% in test series A compared with B, which influences mainly the first phase before maximum intensity is reached. Moreover, a relatively similar maximum intensity is reached for all tests.

In the present work, PT[17,18] were used in the experimental assessment. The standard (PT) was developed for harmonizing the thermal exposure in fire resistance furnace testing and was introduced in the international ISO 834 and the European standard EN 1363-1. The advantages of the PT lie in its ability to record a temperature that is representable to the heating conditions by convection and radiation of the fire exposed test objects. It records an effective temperature which is a weighted average between radiant and convective heat exposures resembling those of test objects. The heat exposure from the combustion chamber to the environment was measured by placing 4 additional PTs in front of the chamber, 3 at a distance 0.5 m, and one 1.0 m from the fire source, see Figure 3. The PT were pointing towards the fire where it should be noted that unless the PT is immersed in the plume the radiant heat flux can be estimated as measure of the radiant impact on the façade.[18]

**TABLE 2** Weight of wood cribs in the tests

| Test | Wall 1 | Wall 2 | Wall 3 |
|---|---|---|---|
| A | 363 kg | 369 kg | 357 kg |
| B | 395 kg | 437 kg | 445 kg |



**FIGURE 3** Position of plate thermometers in front of the combustion chamber [Colour figure can be viewed at wileyonlinelibrary.com]

The results from the measurements 0.5 m from the combustion chamber are presented in Figure 4 as the mean value of the 3 PT. These temperature measurements are closely correlated to the fuel consumption, ie, in the tests with faster fuel consumption the measured plate temperatures are higher, see Figure 5. The temperature was also measured with a PT 1.25 m above the top edge of the fuel chamber, shown in Figure 6. This PT was placed 10 cm from the façade surface and pointing outwards, ie, it measures the incident heat exposure to the façade, as seen in Figure 1. The measurements are generally unstable, and the temperature fluctuates to a large degree. Note that Wall 1 had non-combustible insulation whereas Wall 2 and 3 had combustible insulation adding to the total amount of combustible material.

## 2.2 | SP Fire 105 tests

In SP FIRE 105,[15] the fire source is a tray (width × length × height: 500 mm × 2000 mm × 100 mm) filled with 60 L of heptane. The

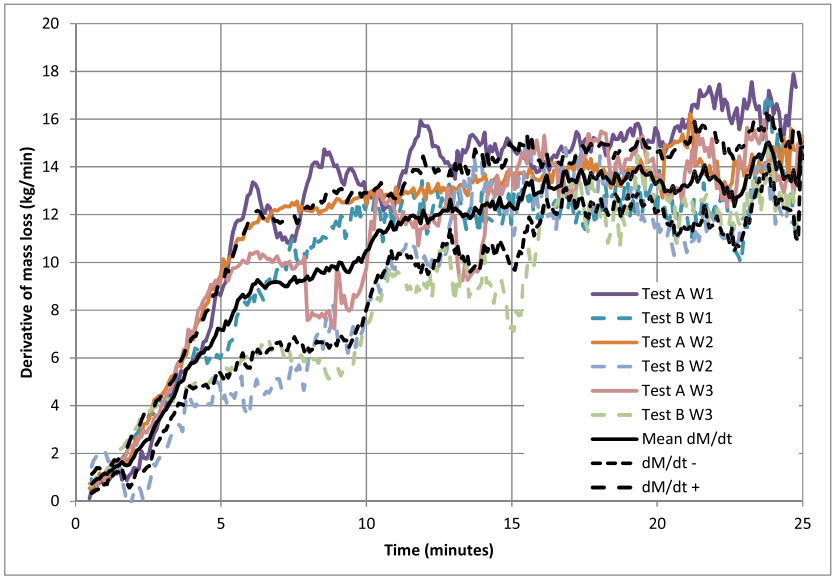



**FIGURE 2** Fuel consumption per time unit during the fire test where WX stands for wall X, including mean and variation (dM/dt − is mean − standard deviation and dM/dt + is mean + standard deviation) [Colour figure can be viewed at wileyonlinelibrary.com]

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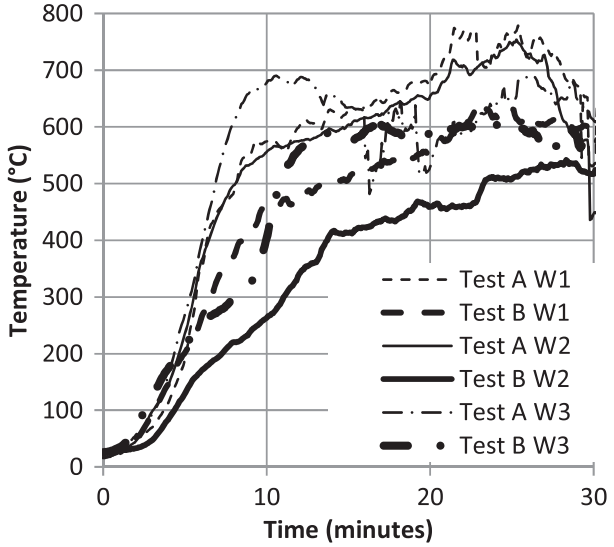



**FIGURE 4** Mean plate thermometer temperature 0.5 m from the combustion chamber where WX stands for wall X

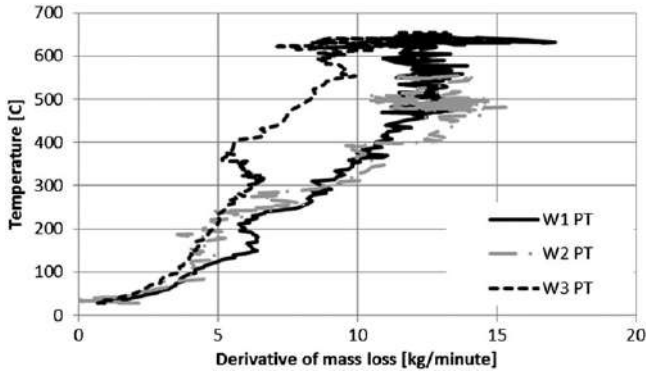



**FIGURE 5** The temperature measured by the centre PT in front of the façade as a function of the derivative of mass loss for the 3 façade specimens in test A

burning of 60 L of heptane with a combustion efficiency of 0.8 corresponds to a fire load of approximately 75 and 280 MJ/m$^2$ in terms of enclosure area and floor area, respectively. In order to create a more stable flame, a flame suppressing lattice consisting of a perforated steel sheet with pipes of 25-mm diameter is placed on the fire tray. It has been classified as a valid test method in Sweden, Denmark, and Norway.[10] During the fire test, 2 thermocouples are placed under an eave, 6 m above the fire room, and a heat flux meter is placed in a lower fictitious window 2.1 m above the fire room.

The SP Fire 105[15] test is carried out indoors in a fire testing hall, and thus the air movements are kept on a very low level. The method is similar to BS 8141-1 with respect to size, although it does not have the wing as the British method. Another difference is the fuel used. BS 8141-1 uses wood, while SP Fire 105 used 60-L heptane, and the height of the combustion chamber is 710 mm in SP Fire 105, while it is 2000 mm in BS 8141-1. Note that there is a significant difference in the total amount of available energy in the 2 fuels, around 4000 to 4500 MJ in the BS 8141-1 test and 1816 MJ in the SP Fire 105 test. Nine tests are presented here, 4 tests of combustible insulation with a protecting render, 3 different wood façade systems with wood impregnated with fire retardants, 1 test with combustible insulation protected with bricks, and 1 directly exposed insulation of phenolic resin, see Table 3.

As in the Zagreb tests described earlier, the thermal exposure out to the environment has been measured 0.5 m from the combustion chamber using 3 additional PT not specified in the test method. The mean temperatures of these PT obtained in each test are presented in Figure 7. The temperature varies between the different tests, and 1 parameter that affects the measured plate temperature is the thickness of the test specimen. Note that in Figure 7 (right), the mean value at 10 minutes is 614°C, and the standard deviation is 54°C; this indicates that the result for the Brick 330 mm (dark blue line) is 734°C, more than 2 standard deviations from the mean indicating that it is the thickness that determines the increased temperature.

The temperature was also measured using a PT pointing outwards 2.1 m above the upper edge of the combustion chamber. The results are presented in Figure 8. Because the test specimens in some cases contribute to the heat production, the measured temperatures are not fully comparable, due to additional combustion of EPS insulation material. In the case with combustible insulation and rendering, the render in some cases cracked and thus combustible gases from the insulation was released and added to the fire.

One test stands out among all tests, namely the test with the very thick façade that consisted of bricks. The measurements show that the PT temperature in front of the combustion chamber (Figure 7) is higher than the other tests, and that the temperature 2.1 m above the combustion chamber is lower (Figure 8). Note that, also the temperature measured by the PT on the Brick 330 façade is more than 2 standard deviations lower than the mean value. This can to some extent be explained by the thickness of the façade system. The radiative heat depends on the thickness of flames. When the thickness of the façade increases, also the length for the flames to reach the façade surface increases, and thus the thickness of the flames seen by the PT. This underlines the fact that PT measure a type of effective surface temperature on a small reference specimen. This effective temperature is a much more representative quantitative measure of the thermal exposure on flat objects than the gas temperature. The thickness of the façade system also affects the energy that will expose the façade surface because some of the energy will be absorbed by the bottom edge of the test specimen, ie, the edge facing downwards and can be seen as an extension of the fuel chamber, as well as the floor and surroundings, see Figure 9. The thicker the specimen is, the more energy will be absorbed by the bottom edge, the floor, and the surroundings. Here, it is also interesting to observe that the flow dynamics is very different for a thicker façade possibly changing the radiated energy to the PT in front of the façade and the radiated and convective heat to the plate on the façade. This effect was possible to verify in numerical experiments using Fire Dynamics Simulation (FDS) where the same qualitative behavior was found and that indeed the flows changed as the thickness of the façade system increased.[19-21] Although, the tests are performed in a controlled environment (indoors) and with varying façade specimen there are some variations in both the exposure to the PT in front of the combustion chamber and the PT on the façade; however, this variation is small compared with the geometrical effect caused by the thicker façade.

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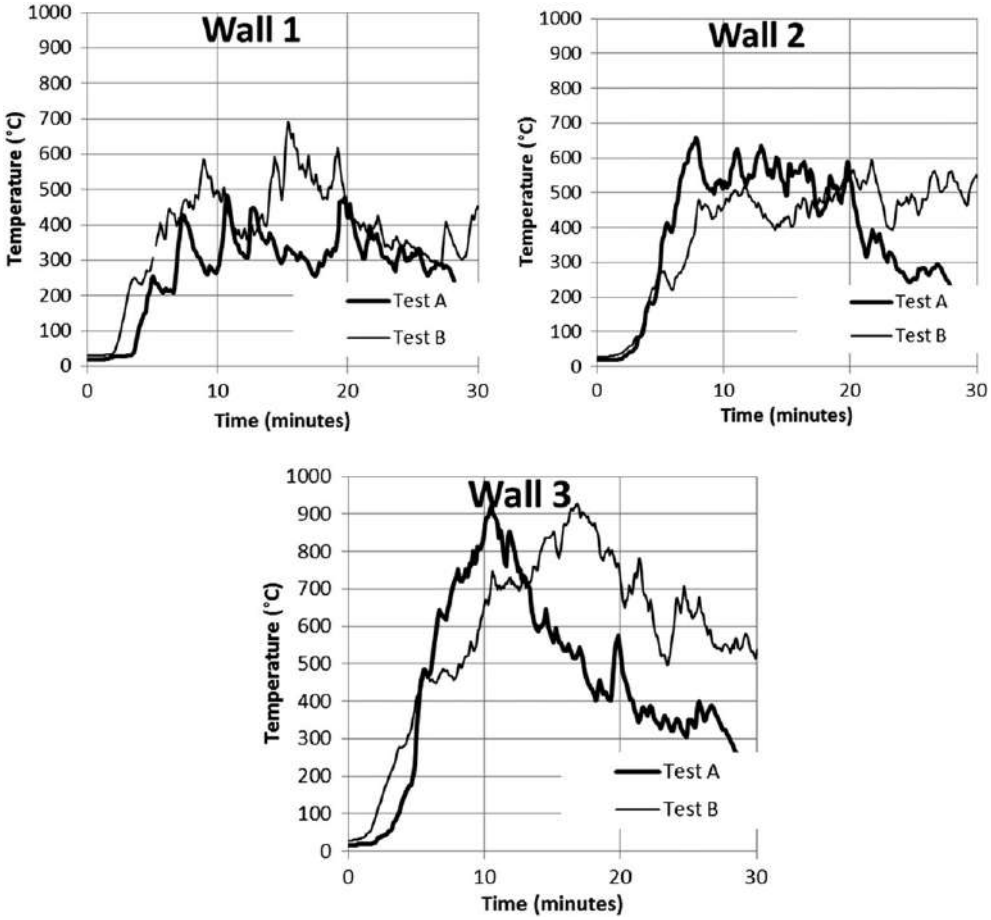



**FIGURE 6** Plate thermometer temperature 1.25 m above the combustion chamber, plate viewing outwards

**TABLE 3** Materials in the SP Fire 105 tests

| Façade, mm | Render etc, mm | Insulation, mm | Total thickness, mm |
|---|---|---|---|
| Render 200 | Render 10 | 200 EPS | 210 |
| Render 212 | Render 12 | 200 EPS | 212 |
| Render 222 | Render 12 | 200 EPS + Paste 10 mm | 222 |
| Render 272 | Render 22 | PIR 250 | |
| Brick 330 | Bricks 117 | Phenolic insul. 168 + Cavity 45 mm | 330 |
| Phenolic Insul. 174 | - | Phenolic insul. 174 | 174 |
| Wood 56 mm | Cedar shingles + spruce plywood 28 | Cavity 28 | 56 |
| Wood 66 mm | Wood panel 21 | Battens and cavity 45 | 66 |
| Wood 67 mm | Spruce 22 | Cavity + studs 45 | 67 |

## 3 | QUALITATIVE MODELING OF THE IMPORTANCE OF THE GEOMETRY OF THE FAÇADE SPECIMEN IN SP FIRE 105

In the numerical part of the present study, the aim is to have visual representation of the effect of the thickness of the specimen tested in SP Fire 105 rig. For this purpose, a model in FDS is constructed using FDS version 6.[19-22] In FDS, the Navier-Stokes equations in the limit of low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires are solved. The algorithm used is an explicit predictor-corrector scheme that is second order accurate in space and time where turbulence is treated by means of large eddy simulation. The heat transfer by radiation is included in the model via the solution of the radiation transport equation for a gray gas. The equation is solved using a technique similar to finite volume methods for convective transport; thus, the name given to it is the finite volume method. When using 100 discrete angles, the finite volume solver requires approximately 20% of the total CPU time of a calculation, a modest cost given the complexity of radiation heat transfer. In order to be able to evaluate variations to the test method, a model was set up in FDS of the SP Fire 105 test rig with the simplifications that the complete back structure of the façade rig is made out of Siporex (lightweight concrete blocks) and that the façade material is constructed of homogeneous blocks with the material data specified in Table 4. The purpose of the

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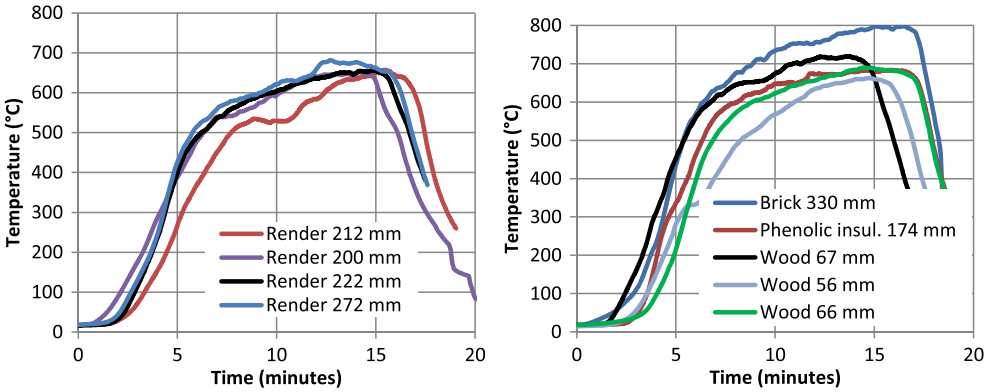



**FIGURE 7** Mean temperature 0.5 m from the combustion chamber as measured by the centre PT shown in Figure 3 [Colour figure can be viewed at wileyonlinelibrary.com]

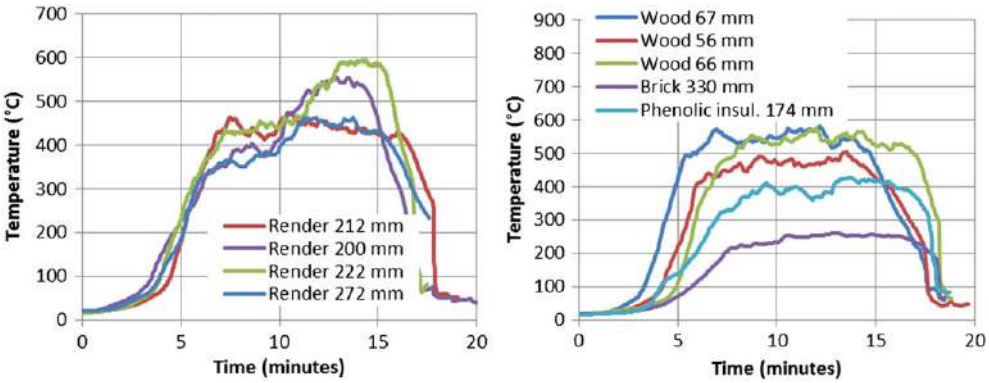



**FIGURE 8** Plate temperature 2.1 m above the combustion chamber, plate pointing outwards [Colour figure can be viewed at wileyonlinelibrary.com]

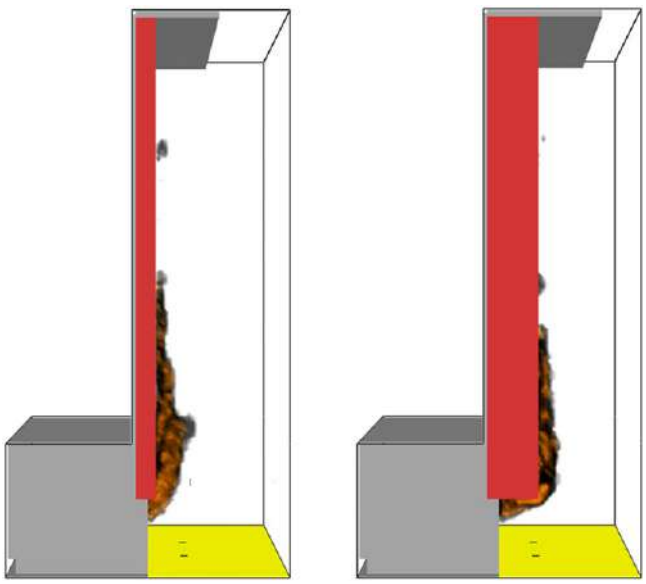


**FIGURE 9** Geometrical factor in the SP Fire 105 test method illustrated in a fire dynamics simulator model [Colour figure can be viewed at wileyonlinelibrary.com]

homogenized façade made of a non-combustible material is to test whether a generalized model can be used to evaluate the performance of the façade system. In order to evaluate the models, measuring

**TABLE 4** Thermal properties of the façade material and Siporex used in the simulations

| Parameter | Façade Material | Siporex |
|---|---|---|
| Thermal conductivity (k [W/(m K)]) | 0.242 | 0.15 |
| Density (ρ [kg/m$^3$]) | 975 | 500 |
| Specific heat capacity (cp [J/(kg K)]) | 1000 | 1000 |

stations corresponding to the measurements made in the experimental work was set up. In particular for realistic comparisons with experimental results, a thermal model for PT[21] was included in the FDS model. The fire source has been added as a prescribed HRR adopted from measurements in Babrauskas.[9] Note that the total energy used in the fire source in BS8414-1 is significantly higher than that contained in the 60 L of heptane used in SP Fire 105.

It is found that the temperature measured with PT in front of the façade is increased with a thicker façade specimen protruding further out from the regular holding rig. Here, it is interesting to note that the reverse behavior is found for the temperature measured by the PT on the wall. This shows the same qualitative behavior as found in the experimental comparison presented below where an increased temperature in front of the façade, and a decreased temperature on the façade 2.1 m above the fire room, is observed as displayed in Anderson et al.[21] The dynamics of the plume and the heat transfer into the façade specimen change due to the thicker specimen, seemingly

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leading to this difference. Due to the extension of the façade, the flows direct the hot gases slightly more away from the fire room closer to the PT in front of the façade and at the same time limit the exposure to the main wall occupied by the specimen. This leads to an increased temperature in front of the façade. The difference in the dynamics is indicated in Figure 9.

## 4 | DISCUSSION AND CONCLUSIONS

In this work, the effects of wind around the test setup are discussed and that it may have a significant impact on the test results. Also, the heat exposure to the test specimen varies to a more limited extent when an uncontrollable free burning fire source is used (in this study heptane and wood respectively) and that this variation increases when wind is present. Note that, 1 additional complication in comparing fire exposure between wood cribs and a heptane pool fire is that the ratio of radiation and convection changes, eg, due to the change in smoke production. The experimental results show that the repeatability is questionable and large variations are present in particular if the tests are performed outdoors such as the case of the BS 8414-1 tests. The results from the 3 different façade systems show that, although the systems are relatively similar, large deviations in the measured temperatures are found due to significant additional combustion occurring in one of the systems and the difference in climate on the 2 test occasions. However, most of this variability comes from the effect of wind and moisture in the wood cribs. The wind creates rhythmic variations in the burning rate whereas increased moisture affects the initial phase of the test. The variations in temperatures measured by 1.5-mm thermocouples at 2.5 and 5.0 m above the combustion chamber are of the order 100°C (at certain times and locations it may be larger for a short period of time) which is caused by the variability in the wind. It is interesting to note the effect of fire stops in the façade; it is indicated that they significantly delay the fire spread along the façade bringing down temperatures to similar levels compared with those found on the façade with non-combustible insulation. Elevated temperatures are found for Wall 3, comparing temperature measurements by PT of Wall 2 (EPS with fire stops) and Wall 3 (EPS without fire stops) along the façade at heights 1.25, 2.5, 3.75, and 5.0 m above the combustion chamber, see Appendix for temperature histories. The maximum fire intensity phase is relatively the same in all tests. Note that, tests performed according to the BS 8414-1 the same materials were tested on 2 different days where large deviations between the 2 test results were found. In the case of SP Fire 105 tests, a set of common façade systems used in Sweden were used as basis for the results. Both methods define an amount of fuel to be used: in BS 8414-1, a volume of wood and in SP Fire 105 a volume of heptane as well as the geometries of the combustion chambers. It is thus not possible to control the heat exposure to the façade surface, and it may be different from test to test due to factors such as air movements around the combustion chamber and geometry of the test samples. For example, the thickness of the test specimen will have an effect because energy will be absorbed by the boundaries before the fire reaches the façade surface and the flow dynamics may change significantly. Naturally, the thickness of the test specimen will affect the exposure because energy will be lost to the surroundings and the underside of the façade system before the fire reaches the vertical façade surface when we define the fire load at the inner edge of the underside of the façade system. Moreover, a specimen that significantly stretches out from the façade rig may change the flow pattern of hot gases out of the fire room and thus change the local fire dynamics and the heat transfer, see Figure 9 and Anderson et al.[21] In order to ensure a robust, repeatable, and reproducible test method for facades, there are several issues that must be resolved. The heat exposure on the façade can for example be defined with PT, which is more linked with the thermal exposure of the façade surface compared with conventional thermocouples. A possible solution is then to prescribe a heat exposure curve, as in fire resistance testing, and use gas burners that can be regulated instead of using a defined amount of free burning fuel. Furthermore, in the SP Fire 105 method combustion of internal components in the façade system is in practice checked by visual means. It would be preferable to assess internal combustion using distinct measurements with, eg, thermocouples.

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## APPENDIX

In the appendix, further results are summarized regarding test performed according to BS 8414-1, at 4 positions at the centerline at 1.25 m (Figure A1), 2.50 m (Figure A2), 3.75 m (Figure A3), and 5.00 m (Figure A4) height above the combustion chamber. Note that Figure A1 summarizes all the results in Figure 6. In the Figures A1 to A4, Wall 3 (including EPS insulation without fire stops) stands out in terms of having elevated temperatures along the façade main face up to the measurement point 5.0 m above the combustion chamber. It is indicated that appropriately fitted fire stops slow the fire spread significantly at all heights because there is a significant difference in the measured temperatures between W2 (EPS with fire stops) and W3 (EPS without firestops).

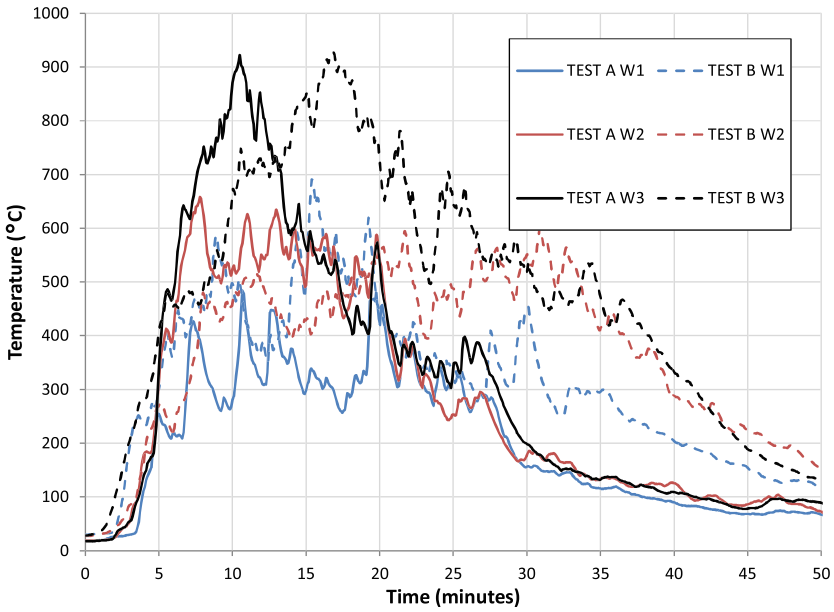



**FIGURE A1** Plate thermometer temperature 1.25 m above the combustion chamber, plate viewing outwards. WX denotes for Wall X [Colour figure can be viewed at wileyonlinelibrary.com]

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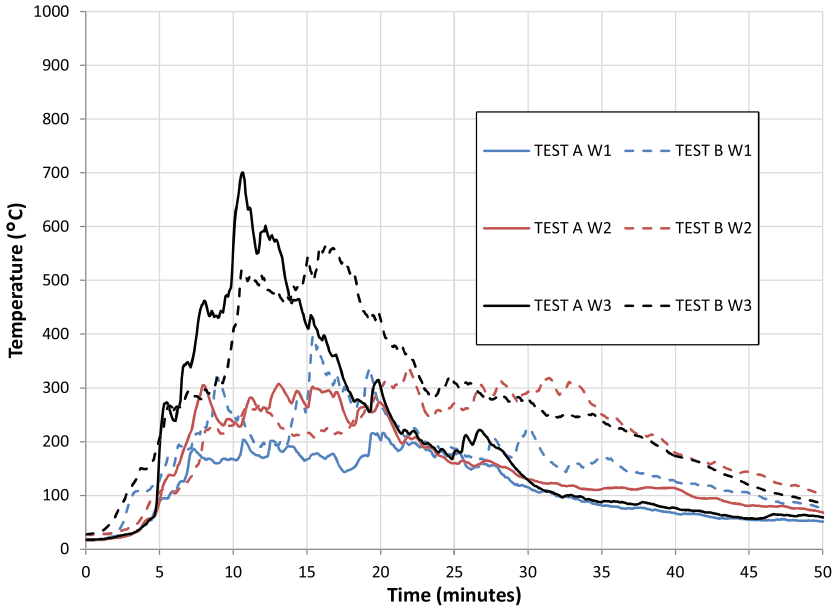



**FIGURE A2** Plate thermometer temperature 2.50 m above the combustion chamber, plate viewing outwards. WX denotes for Wall X [Colour figure can be viewed at wileyonlinelibrary.com]

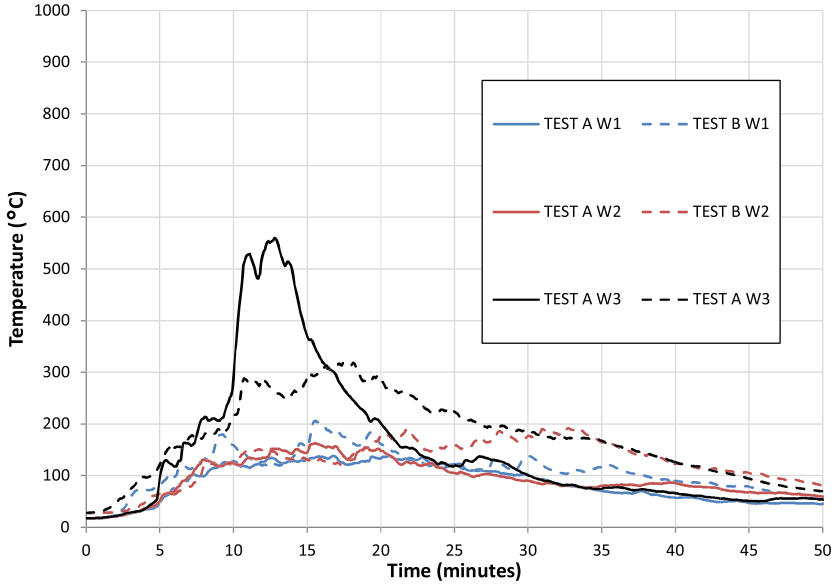



**FIGURE A3** Plate thermometer temperature 3.75 m above the combustion chamber, plate viewing outwards [Colour figure can be viewed at wileyonlinelibrary.com]

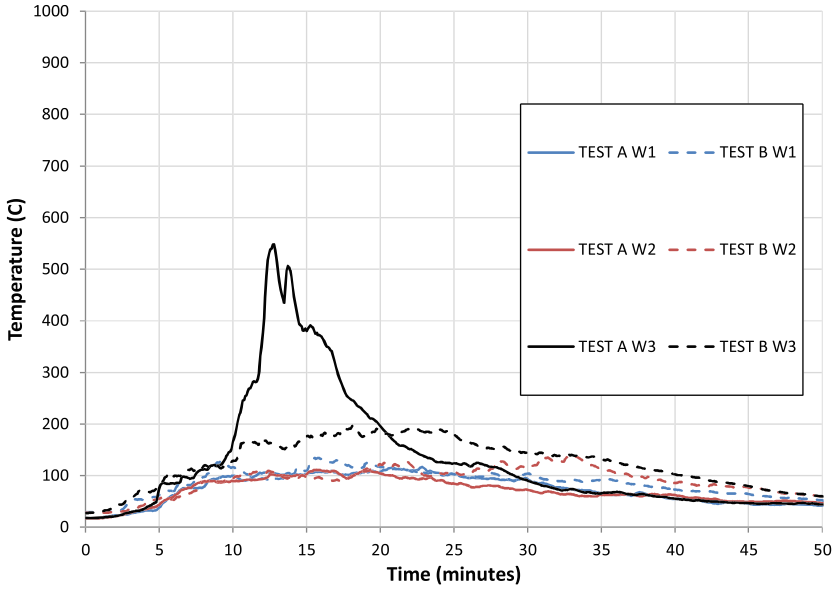



**FIGURE A4** Plate thermometer temperature 5.00 m above the combustion chamber, plate viewing outwards [Colour figure can be viewed at wileyonlinelibrary.com]

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