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Article

Using the ISO 9705 Room Corner Test for Smoke Toxicity Quantification of Oriented Strand Board

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Abstract: As smoke toxicity is unregulated outside of the mass transport industry, there is no set methodology for assessing smoke toxicity of construction products, like OSB, on a large-scale. This research aims to assess the novel design of a modified ISO 9705 room corner test designed for smoke toxicity quantification. Three tests conditions will be assessed to determine if restriction of ventilation is enough to force a fire to transition to under-ventilated flaming, or if the fuel loading is much more important in affecting the fire severity and fire condition. The research found that fuel loading and test geometry has more significant impact on the fire condition than restricting the ventilation. While imposing restrictions on the test rooms ventilation did increase the equivalence ratio, it was not sufficient enough to force the transition into under-ventilated flaming. The addition of a door to the test room did not force the fire to transition to under-ventilated flaming. When doubling the fuel loading, there was sufficient fuel for the fire to transition to under-ventilated flaming. This research has provided the experimental methodologies to assess smoke toxicity at a range of ventilation conditions on a large-scale.

Keywords: smoke toxicity; large-scale; Oriented Strand Board; ISO 9705; flammability

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Introduction

Oriented Strand Board (OSB) has become increasingly prevalent in the construction industry due to its affordability, structural reliability[0], and sustainable qualities[2]. However, despite its widespread application[3], OSB is a flammable material which produces toxic fire effluent upon decomposition[4]. However, as smoke toxicity is unregulated outside of the mass transport industry, there is no set methodology for assessing smoke toxicity of construction products, like OSB, on a large-scale. The ISO 9705 room corner test[5] primarily assesses the flammability of materials[6] and as the materials are mounted to the walls during a test and is not suited for smoke toxicity assessment. Additionally, little research is published surrounding how to force under-ventilated fire conditions when conducting large-scale tests. Smoke toxicity is typically most dangerous during post-flashover under-ventilated fires, and so the need for a methodology to assess the most toxic scenario is needed to determine the best, and worst case scenarios construction products may be exposed to.

This research aims to assess the novel design of a modified ISO 9705 room corner test designed for smoke toxicity quantification. Additionally, three tests conditions will be assessed to determine the best methodology for testing in well-ventilated, and under-ventilated fire conditions. This research seeks to determine if restriction of ventilation is enough to force a fire to transition to under-ventilated flaming, or if the fuel loading is much more important in affecting the fire severity and fire condition. The research also aims to assess if the proposed configuration and modifications to the ISO 9705 room are suitable for providing a methodology for large-scale assessment of smoke toxicity. The test designs used are novel and have not been based on any previous testing conducted in literature.

Method

The methodology used is identical to that of other published large-scale work by the author(s). The tests were all conducted in a series over a short time-period.

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Gas analysis and fire condition measurements

Three stainless steel tubes with an internal diameter of 6 mm were secured near the top of the doorway. One was used as a sampling line for a phi meter that was specifically designed and created to monitor the equivalence ratio[7]. The two remaining sampling lines went to a specially made portable gas analyser, designed and created for this work (containing an NDIR, and O_2 electrochemical cells). The three tubes were placed approximately 0.1 m from the ceiling pointing upwards and were approximately 0.3 m across the doorway.

Silicone tubing was connected to the stainless steel tubing at the bottom. The stainless steel tubes were approximately 1 m in length. This allowed the effluent to cool slightly before using silicone tubing connections to the analysers and prevented the tubing from melting during testing. The silicone tubing was connected to a glass tube filled with glass wool to filter the soot from the sample gas to prevent blockages inside the analysers. The analyser sampled O_2, CO and CO_2 continuously at a flow rate of 1 L min^{-1}.

The phi meter sampling line was connected to the third stainless steel tube in the doorway. Silicone tubing was attached to the stainless steel tube. A glass tube filled with glass wool to act as a filter was attached to the silicone tubing. The filter was attached to an Omega 3100 series 0-5 L min^{-1} flow meter set to a regulated flow of 1.5 L min$^{-1,}$ followed by a Charles Austen d5 SE air pump. The gas was then split into two lines using a glass T-piece. One line was connected directly to an exhaust, the other was connected to the sample inlet of the phi meter. This minimised sampling time delays due to the very low flow rates used in the phi meter for analysis. The sampling was continuous throughout the tests.

As silicone tubing was used, there is likely to be losses occurring during sampling. Use of a heated line would have eliminated any potential losses; however a heated line was unavailable for this work and so while preferable, one was not used.

Monitoring air flow and temperature

The airflow in the doorway was monitored to enable gas yields to be calculated (alongside using the mass loss) for reaction products produced and measured during the test. Air velocity in and out of the door was monitored using bi-directional McCaffrey probes (McC)[89] with a differential pressure transducer at the end. The pressure transducers were obtained from Farnell components. A Sensirion CMOSens SPD1000-LO25 pressure transducer was attached to the end of silicone tubing attached to the McCaffrey probe. The pressure transducer was connected to a 5 V power supply, and the signal wires were connected to a data logger to log the voltage output of the pressure transducer. The probes were placed in the doorway at set heights. The heights have been summarised in Table 1. The probes were placed approximately 0.2 m into the doorway for each test.

The gas velocity profile in the test doorway was calculated by using the measurements obtained by the probes alongside the temperature profile data obtained from the thermocouple tree[10] located in the centre of the doorway.

Table 1. Summary of the heights where the McCaffrey probes were placed during testing. The distance was measured from the ceiling.

	McCaffrey probe height from the ceiling /m		
Test condition	**1**	**2**	**3**
Well-ventilated	1.5	1	0.5
Under-ventilated	0.5	0.3	0.1

Standard measurements

All standard room corner measurements were taken throughout the experiments as described in ISO 9705. Oxygen was monitored using a paramagnetic analyser, and CO/CO_2 was monitored using an infrared spectrophotometer within the analysis system. Additional measurements also

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included duct flow, temperature, smoke obscuration, air pressure, humidity and temperature. Heat release is calculated by the test room software. Systems were logged by a VeeCan DAQ system.

All standard room corner measurements were logged every 3 seconds. The additional gas analysis systems used for the experiments were logged every 1 second. Consequentially, the two time scales were required to be matched afterwards.

Test layout and fuel loading

OSB sheets were attached to a singular single burning item (SBI) rig[11] with a 4 mm air gap between the material and the calcium silicate boards. The board was approximately 12 mm thick and slightly raised above the burner, as in the SBI test. Three separate tests were carried out: 1xSBI (no door), 1xSBI (door), and 2xSBI no door. The 1xSBI (no door) test was used to replicate well-ventilated flaming conditions. The 1xSBI (door) test was performed to see if restriction of the ventilation would force under-ventilated flaming conditions. The 2xSBI (no door) test was performed to see if doubling the fuel loading would result in under-ventilated flaming conditions.

One SBI rig was set up for both 1xSBI tests. A total mass of 14.72 kg and 14.59 kg of OSB was used for the 1xSBI (door) and 1xSBI (no door) tests respectively. The SBI rig was placed on the load cell in the centre of the ISO room. Gas analysers were calibrated and set up for testing. Heptane was measured out and poured into the burner(s) inside the room. The ISO room measurements were started alongside the gas analysers and phi meter 2 minutes before ignition. The heptane burner was ignited manually. In the 1xSBI (door) test, a 1.3 m door was placed over the bottom part of the door of the ISO room after ignition to restrict the ventilation into the room. The 2xSBI (no door) test was performed identically, however the two SBI rigs were set up (facing one another) and the total mass of OSB used was 30.65kg.

The airflow was monitored using McCaffrey probes throughout the test. In this test, the lower McCaffrey probe was altered so that the inlet to the probe was facing outwards to record the airflow into the test room. The data was recorded for future use for calculations of the volume flow of gas in the doorway to be used for yield calculations. The yield calculations are beyond the scope of this paper.

Results

Heat release

The heat release data from the tests are shown in Figure 1. The heat release data is shown with the inclusion of the heat released from the ignition source.

In the test using 1x SBI with no door, the heat release rose to 300 kW rapidly after ignition, which is likely a result of the heat release from the heptane burner and the ignition of the OSB sheet. From 250 to 450 seconds, the heat release was relatively steady. At 500 seconds, the heat release rose rapidly again, reaching its peak heat release of 990 kW at approximately 700 seconds into the test. At this point, the entire OSB sheet was burning. After reaching its peak, the heat release dropped rapidly. This was likely a result of the OSB becoming burnt through, meaning there was no fuel left to facilitate the fire.

In the test using 1x SBI with a door, the heat release rose rapidly after ignition and reached the peak heat release of 670 kW at 720 seconds into the test. At 725 seconds, the heat release dropped rapidly before gradually declining as the fuel began to run out. The heat release with the restricted ventilation was much lower.

In the test using 2x SBI with no door, the peak heat release of 1180 kW was reached at 420 seconds into the test. The sharp rise was thought to be due to a radiant effect from the two SBI rigs facing each other after both were fully flaming, or a result of both sides of the OSB flaming at once. The rigs facing each other forced the fire to be much more severe than using 1x SBI.

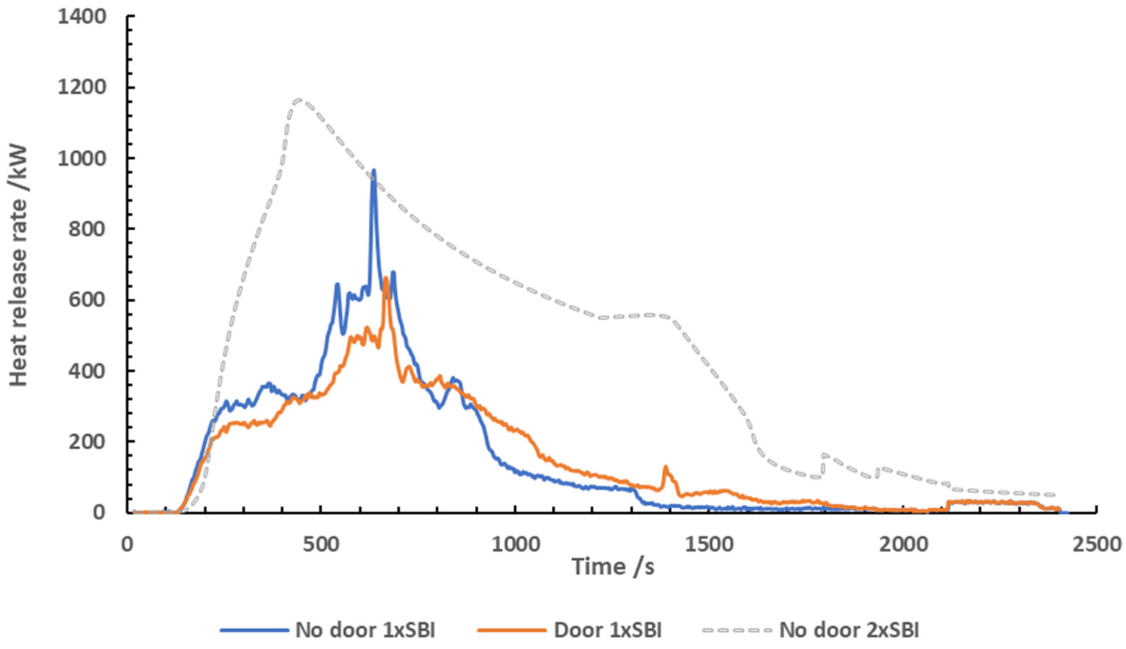

Figure 1. Heat release measurements taken when testing OSB in the ISO 9705 room corner using 3 different test set-ups.

The HRR curves for 1 x SBI where the doorway was fully open and shut off show remarkable similarity, including a similar peak occurring at 640 seconds. This was presumably when both sides of the OSB were burning at the same time. However, the peak HR for the partially blocked doorway is around 670 kW, rather than 990 kW for the open doorway. This demonstrates the effect of partially blocking the door to the ISO room is slowing the rate of burning, rather than forcing under-ventilated flaming. The peak heat release measured decreased with the addition of the door on the test room. This was likely a result of the calcium silicate board used as the door absorbing a portion of the heat from the fire, resulting in a lower heat measurement.

Mass loss

The mass loss measured using the scale in the test room for each test is shown in Figure 2.

As the test using 1x SBI with no door only used one rig, the test rig's total mass was within the range's limits. The mass loss measurements showed a steady decline over the course of the entire test, with the mass reducing to approximately from 118 kg to 100 Kg by 800 seconds.

The data obtained when testing 1x SBI with a door has been presented, however it is thought that the scale did not appear to provide an accurate mass loss measurement as the mass appears to only change by approximately 15 Kg. As the majority of the weight was from the steel frame, it is difficult to see the actual mass loss that occurred during the test, although the mass was seen to steadily decline over the course of the test. The mass of the residue at the end of the test was unfortunately not recorded.

The initial measurement of the test using 2x SBI with no door was not recorded due to the test rig exceeding the maximum measurement of the scale (165 kg). The mass had reduced enough by 420 seconds to measure the actual mass loss occurring. The largest mass loss was observed at 320 seconds to 420 seconds. The plateau observed from 400 onwards is a result of a slow smouldering fire occurring after the test had finished.

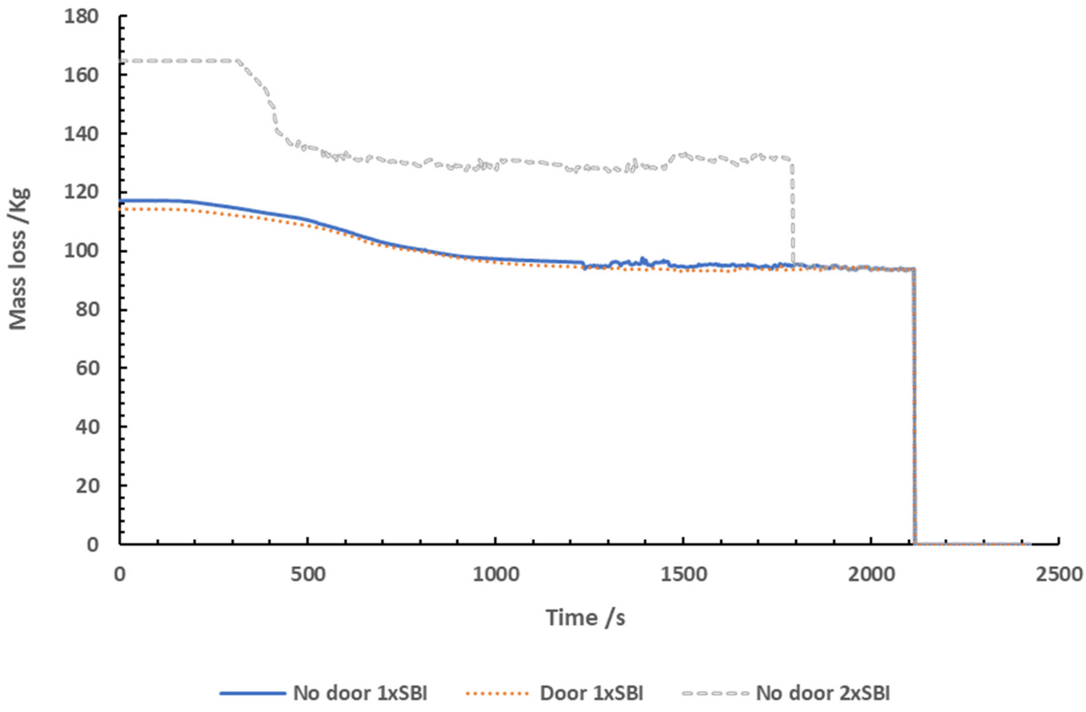

Figure 2. Mass loss measurements taken using the scale in the ISO room corner test when testing OSB.

Temperature

Temperature measurements were taken in the doorway of the ISO room throughout the tests. The temperature profile recorded can be used in the future to identify the neutral plane within the doorway to calculate air velocity in and out of the room with the addition of air velocity measurements. Within the temperature data, a clear distinction between the upper and lower plane in the doorway was seen. The upper plane can be seen from 40 cm from the ceiling down to 80 cm from the ceiling. The lower plane is seen from 100 cm to the bottom of the room. The thermocouple at 80 cm sits in the middle of the two planes. This was taken as the neutral plane point and can be used to calculate gas yields measured in the doorway for future work.

The temperatures measured when testing 1x SBI with no door increased rapidly upon ignition, reaching a maximum temperature of 590 °C approximately 650 seconds into the test. After reaching its peak, the temperature began to slowly decline as the fire began to decrease. The peak temperature measured corresponds to the same point the peak heat release was measured during the test.

The temperatures measured when testing 1x SBI with a door show a rapid increase upon ignition, reaching a maximum temperature of 580 °C before slowly declining as the fire begins to decrease. The temperature profile was used to identify the neutral plane to calculate air velocity in and out of the room. As the door covered the bottom third of the door, the measurements taken more than 80 cm from the ceiling are negligible.

When testing 2x SBI with no door, the peak temperature was 900 °C, measured 40 cm below the ceiling. The excess heat produced from the fire was likely a result of radiant effects occurring as the two burning test rigs faced each other, causing an increase in the overall heat measured inside the room.

Fire condition

The equivalence ratio was logged throughout the tests using a phi meter [7]. The results obtained are shown in Figure 3.

After ignition, the equivalence ratio measured using 1x SBI with no door grew steadily, reaching a peak value of 0.71 approximately 650 seconds into the test, corresponding to the same time the peak heat release was reached. The equivalence ratio remained below 1 throughout the test, showing that the fire remained well-ventilated for the test duration. For most of the test, the equivalence ratio remained between 0.3 and 0.7, which is representative of early well-ventilated flaming. This was likely a result of the open door, as fresh air could enter the fire allowing for more complete combustion to occur throughout. After 650 seconds, the equivalence ratio begins to decline as a result of the lack of fuel. While the HRR data shows a sharp peak at 680 seconds, the phi meter peak is much softer. This is a result of the slower response time of the phi meter, resulting in a softer peak being measured.

The peak equivalence ratio measured when testing 1x SBI with a door was 0.95 and was reached 610 seconds into the test. The equivalence ratio rose steadily upon ignition, however the fire did not transition into under-ventilated flaming despite the door restricting the ventilation of the test room.

Upon ignition, the equivalence ratio grew rapidly when testing 2x SBI with no door, reaching a peak value of 1.50 at 400 seconds into the test. The fire was able to transition fully into under-ventilated flaming due to the significant amount of fuel present in the test room and the high heat release. Under-ventilated flaming was sustained between 300 to 420 seconds. After this point, the fuel became limited, and the fire began to decrease in size, seen by a decrease in equivalence ratio.

When the maximum equivalence ratio was reached, flaming combustion occurred in the doorway due to the severity of the test, and so the stainless steel sampling lines were sampling from the flame zone within the doorway. This means that while the fire was clearly under-ventilated, the measurements taken may not be truly representative of the actual burning conditions occurring inside of the room.

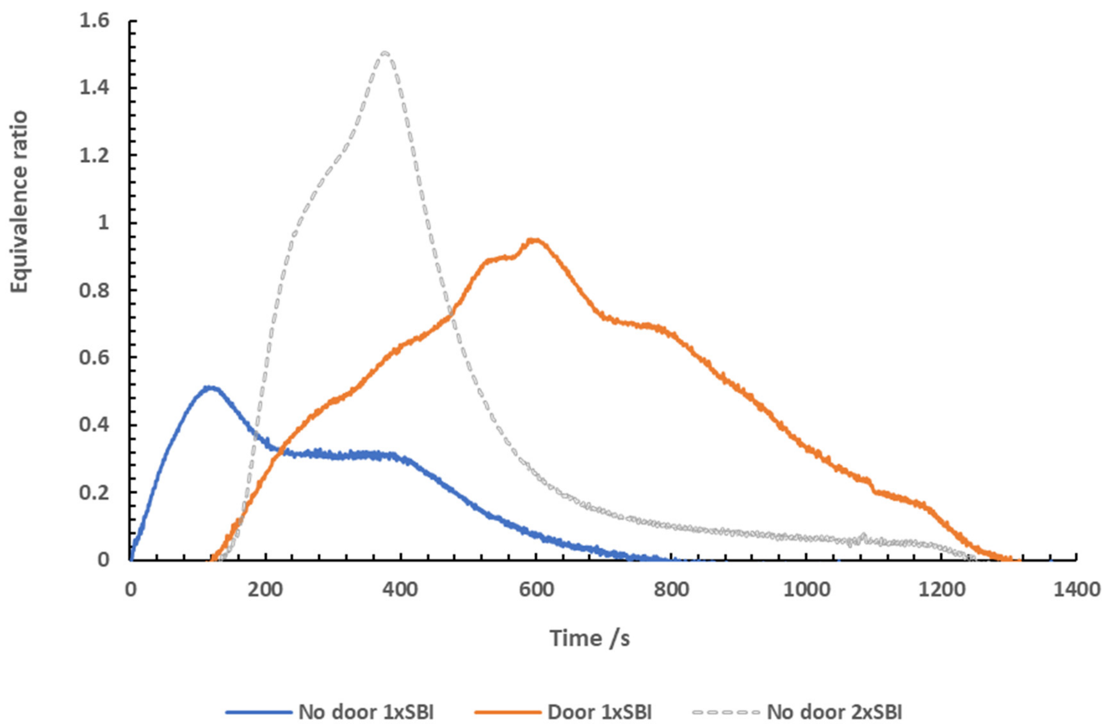

Figure 3. Equivalence ratio monitored using a phi meter when testing OSB in the ISO room corner.

Oxygen measurements

The oxygen measured in the door and exhaust duct throughout the tests is shown in Figure 4.

After ignition, the oxygen levels in the door began to decline rapidly before settling between 12 to 13 % for around 200 seconds when testing 1x SBI with no door. As the fire progressed, a significant drop in oxygen was observed, reaching 5.5 % in the door at 650 seconds. This corresponded with the time at which the equivalence ratio and the heat release was at its highest. The oxygen did not stay below 10 % for longer than 50 seconds. For the duration of the test, the oxygen predominantly settled between 10 to 15 %, indicating the fire was well-ventilated. The oxygen concentration measured in the exhaust duct did not significantly change from its baseline value. This was likely due to the excess dilution occurring from the large flow rate used in the extraction hood causing significant dilution to the measurements taken.

When testing 1x SBI with a door, the oxygen concentrations measured in the door dropped rapidly upon ignition, gradually lowering to 2.5 % at 620 seconds. The oxygen concentrations remained below 15 % throughout the middle of the test. In the duct, the oxygen concentration did not deviate significantly from baseline values.

After ignition of the 2x SBI (no door) test, the oxygen levels in the door begin to decline rapidly. The oxygen in the exhaust duct dropped to 16.5 % approximately 200 seconds into the test, with the door measurements dropping to 2 % comparatively. At 350 seconds into the test, the oxygen measurements in the doorway dropped to 0 %, and remaining that low for 200 seconds. The sampling at this point was occurring within the flame zone as the flames from the fire were seen to be exiting the doorway during this time. The oxygen concentrations in the exhaust duct fell to 5 % at approximately 400 seconds into the test. The concentration was higher than that measured in the door from a combination of the excess air flow being drawn into the exhaust duct, as well as the sampling not occurring within the flame zone. The concentrations measured in the exhaust duct and the doorway were representative of under-ventilated flaming. After 400 seconds, the fire began to run out of fuel, resulting in less flaming combustion occurring. This allowed more oxygen to enter the room and the oxygen concentrations were observed to rise gradually until baseline values were reached.

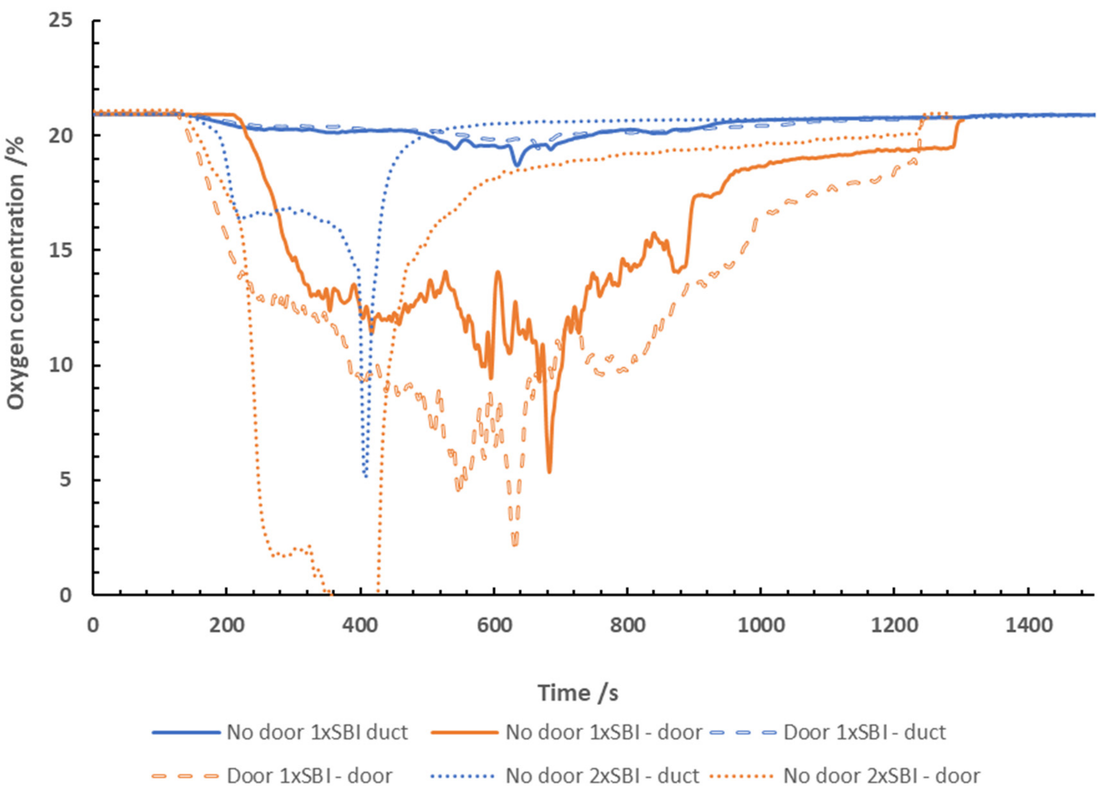

Figure 4. Oxygen measurements taken in both the door and duct of the ISO room corner when testing OSB in 3 conditions.

CO_2 measurements

The CO_2 concentrations logged in the exhaust duct throughout the test is shown in Figure 5.

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When testing 1x SBI, the measurement of CO_2 in the doorway were not logged for this test due to an error in the test equipment, and so the CO_2 concentration in the doorway was calculated by multiplying the duct measurement by 4 (the approximate dilution factor). The CO_2 increased after ignition occurred, rising to a predicted peak concentration of 7 % in the doorway, and a peak concentration of 1.7 % in the exhaust duct. The peak concentrations were reached approximately 650 seconds into the test. The dilution resulted in concentrations in the doorway being approximately 2.5 times more concentrated than those measured in the exhaust duct. The CO_2 concentrations reached in the doorway are representative of well-ventilated flaming.

The concentration measured became relatively stable from 400 seconds to around 700 seconds. The decline in CO_2 at 700 seconds occurs rapidly, and concentrations decline to baseline values. This was the point at which the fire began to slow down due to a lack of fuel.

When testing 1x SBI, due to a measurement issue in the doorway, the CO_2 concentrations were not logged. The doorway measurement was calculated using the exhaust duct data multiplied by the dilution factor (4). The CO_2 measured in the exhaust duct remained relatively low, reaching its peak concentration of 1.2 % at approximately 620 seconds into the test. Overall, the CO_2 measured was relatively stable and steady. The CO_2 measured in the door reached a calculated peak concentration of 4.45 % 620 seconds into the test.

When testing 2x SBI with no door, the CO_2 concentrations measured in the exhaust rose rapidly upon ignition, reaching a concentration of 5.8 % in the exhaust duct at 200 seconds. The concentration plateaued, until another sharp rise in concentration was observed at 400 seconds, reaching 14 %. Similarly, the CO_2 in the doorway rose rapidly upon ignition, reaching a concentration of 14.8 % and plateauing for approximately 40 seconds before rising again, recording a peak concentration of 16.8%. This is towards the upper limit of the measurable range of the NDIR used in the analysis system. However, it is also indicative of more CO_2 being formed after it passed the doorway.

The CO_2 concentration declined rapidly after reaching the peak concentration as a result of the fire running out of fuel. The CO_2 concentrations measured in the door were indicative of under-ventilated flaming occurring. The point at which the CO_2 concentrations were at their highest coincides with the point at which the equivalence ratio was at its highest, and the oxygen concentration was at its lowest.

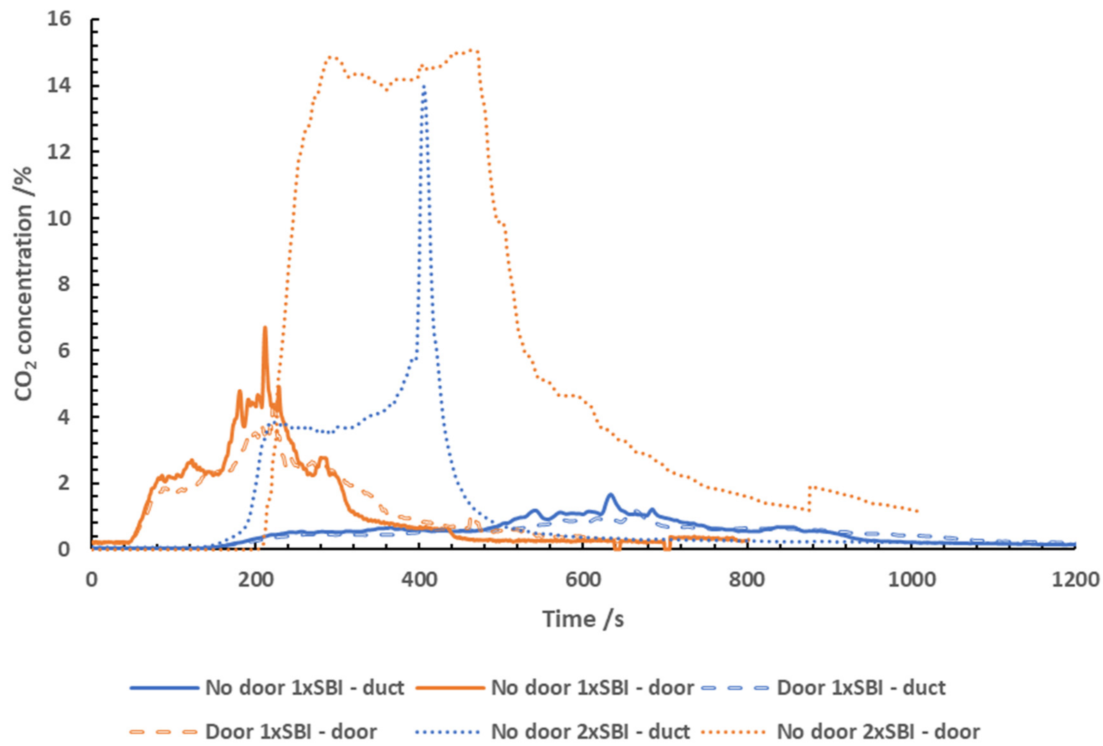

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Figure 5. CO_2 measurements taken in duct and doorway of the ISO room corner when testing OSB. For the 1xSBI no door test, the predicted CO_2 concentration of the doorway measurement are shown.

CO measurements

The CO concentrations measured throughout the test are shown in Figure 6. Due to a measurement issue, the CO was not logged in the doorway during the test conducted using 1x SBI with no door. The CO measurement of the doorway was calculated using the exhaust duct values multiplied by 4 (the approximate dilution factor). Overall, the CO measured in the exhaust duct was substantially lower than that measured in the door. The CO concentrations remained low for the first 500 seconds of the test. The CO concentration in both the doorway (calculated) and exhaust duct peaked at 580 seconds, and again at 680 seconds. In the first initial peak, the CO concentrations reached 0.1 % in the exhaust duct, and 0.4 % in the doorway (calculated). In the second peak that occurred at 580 seconds, the CO reached 0.12 % in the exhaust duct, and 0.48 % in the doorway.

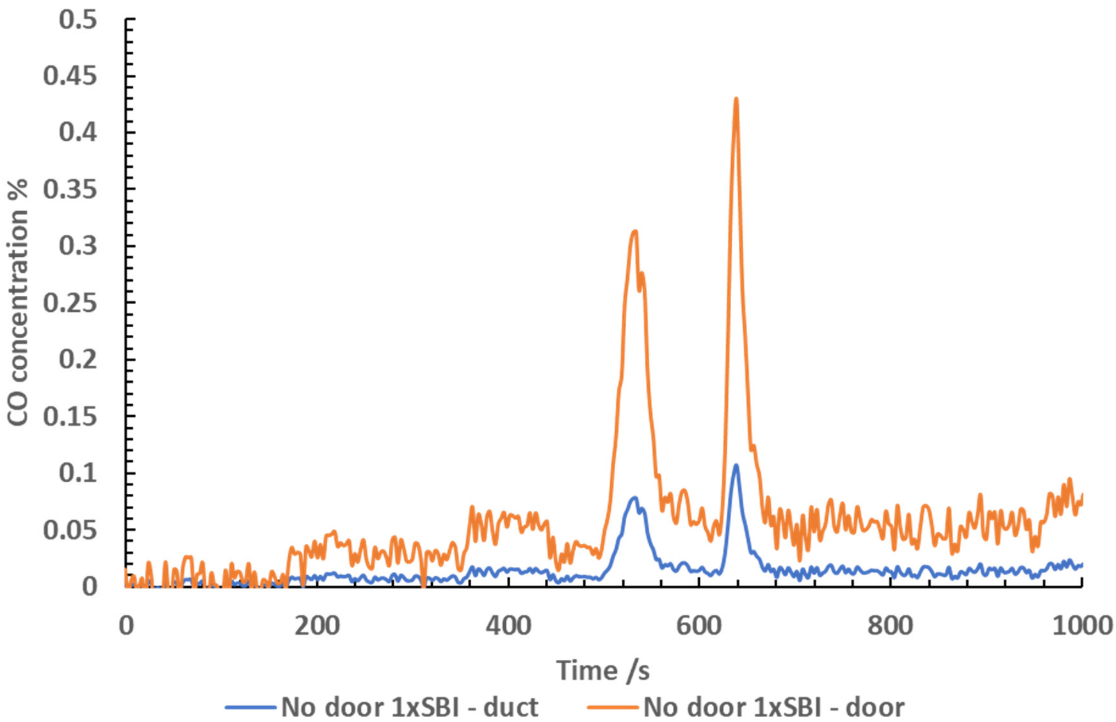

Figure 6. CO measurements taken in the exhaust duct of the ISO room when testing OSB (1x SBI no door), shown with a calculated doorway concentration found by using the duct measurement multiplied by the dilution factor (4x).

The CO measurements taken when testing 1x SBI with a door in the door and exhaust duct are shown in Figure 7. Due to a measurement issue in the doorway, the concentrations of CO were not logged. The CO presented is a calculated value using the exhaust duct data multiplied by the dilution factor of 4. The CO in the exhaust duct was similar to the concentrations measured in the door. The door measured slightly higher concentrations of CO, with a peak concentration of 0.09 % at 600 seconds into the test, shortly after ignition. At this point it was calculated that the concentration in the doorway was 0.34 %. A peak concentration of 0.075% was reached in the exhaust duct at 700 seconds into the test, and 0.3 % in the doorway.

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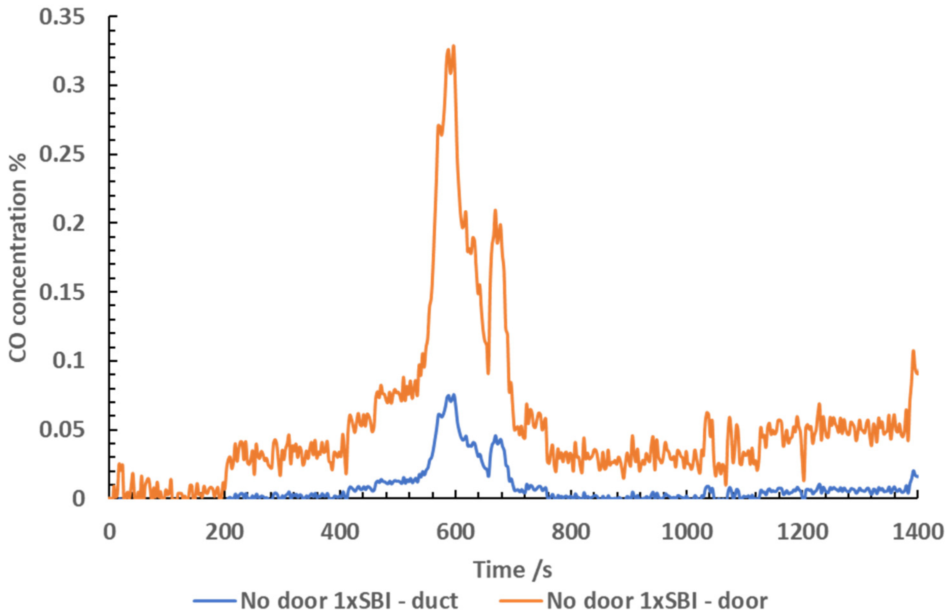

Figure 7. CO measurements taken in the door and exhaust duct of the ISO room when testing OSB (1x SBI with door).

The CO concentrations logged when testing 2x SBI no door are shown in Figure 8. The CO concentrations measured rose rapidly upon ignition, reaching a concentration of 5.8 % in the doorway at 200 seconds. Similarly, the CO in the duct rose rapidly upon ignition, reaching a concentration of 2.6 %.

The CO concentration declined rapidly after reaching the peak concentration as a result of the fire running out of fuel. The CO concentrations calculated for the door were indicative of under-ventilated flaming occurring. The point at which the CO concentrations were at their highest coincides with the point at which the equivalence ratio was at its highest, and the oxygen concentration was at its lowest.

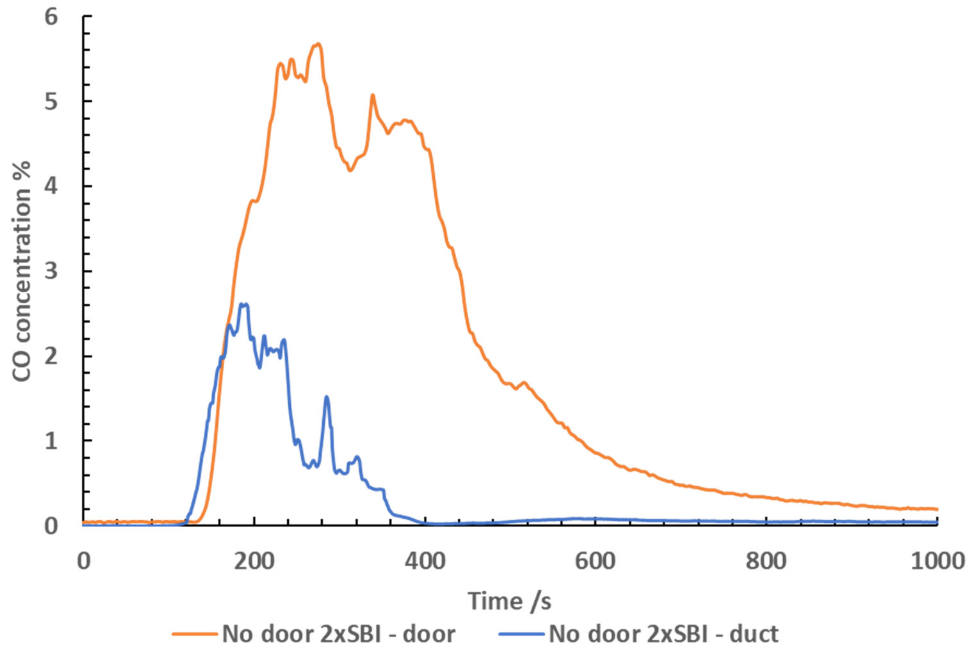

Figure 8. CO_2 measurements taken in the door and exhaust duct of the ISO room when testing OSB (2x SBI no door).

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Summary

The data obtained from the three tests has been summarised in Table 2.

Table 2. A summary of the data obtained from testing OSB in the ISO room using several different test configurations for different fire conditions.

	No door 1xSBI		Door 1xSBI		No door 2xSBI	
Test Measures	*Duct*	*Door*	*Duct*	*Door*	*Duct*	*Door*
Lowest O_2 /%	18.7	5.3	19.5	1.9	5.2	0
MaximumCO_2 /%	1.7	6.7	1.2	4.6	14	15.1
Maximum CO /%	0.12*	0.48	0.09*	0.36	0.9	5.1
Peak heat release /kW	990		760		4500	
Maximum equivalence ratio /ϕ	0.70		0.95		1.50	

*indicates calculated value using exhaust duct data.

During both tests conducted using 1x SBI, the fire effluent slowly rose to the ceiling and a smoke layer developed in the test room. As the fire progressed, the effluent became diluted with plenty of fresh air entering the room and mixed with the fire effluent. As the test continued, the hot smoke layer grew and was observed to leave the room in a plume 40 to 70 cm down from the ceiling. When no door was used, the fuel loading in the test was limited and so the fire did not transition to under-ventilated flaming. Using the door to restrict the ventilation resulted in the door absorbing some of the heat from the fire. Combined with the low fuel loading, the test did not reach under-ventilated flaming. Therefore the use of a door (1/3 of the opening restricted) to restrict ventilation is not sufficient to force a fire to transition to under-ventilated flaming. As the smoke was extracted from the room, the fire could continue growing until all the available fuel ran out due to the availability of oxygen from the open and partially open doorway. The smoke produced was relatively clean with only small amounts of sooty smoke being observed. For both tests, the oxygen, CO and CO_2 data were all representative of well-ventilated flaming conditions, which were in agreement with the equivalence ratio measurements taken throughout the test.

When using 2x SBI (doubling the fuel loading), the fire started off well-ventilated. As the fire continued to grow, the upper smoke layer grew and descended in the room. As the fire progressed, the smoke layer started to pour out of the doorway. As the equivalence ratio surpasses 1, the fire visibly transitioned to under-ventilated flaming where the flames were seen to reach the room's ceiling. The concentration of air entering the fire began to decrease. This continued as the equivalence ratio increased.

During the test, the flames descended below the smoke layer. This is typical in fires where the size of the room is the limiting factor. At this point, the smoke layer began to descend until it reached a steady burning period. During this point, oxygen concentrations in the door dropped below 1%, reaching 0% at their lowest. At this point of the test, the flames were pouring out of the door, passing over the stainless steel sampling lines. The measurements were taken in the flame zone, so it is likely that the effluent sampled underwent further chemistry later in the exhaust duct.

The peak equivalence ratio reached was 1.5. The peak aligns with the point at which CO concentrations measured at the door are at their highest, and where the oxygen concentration in the door dropped to its lowest.

Conclusions

Conducting three different test scenarios on the same material has allowed for the identification of test conditions to be made in regards to controlling the ventilation of the test. In large-scale testing, particularly when using the ISO room, fuel loading and test geometry has more significant impact on the fire condition than restricting the ventilation. While imposing restrictions on the test rooms ventilation did increase the equivalence ratio, it was not sufficient enough to force the transition into under-ventilated flaming. Using three different test configurations allowed for different experimental set-ups to be assessed to identify what is needed to achieve specific burning conditions in the ISO room corner test. The use of 1x SBI rig with no door meant that the fire had enough ventilation and fuel to burn well-ventilated. This was evidenced by the equivalence ratio of 0.7. The heat release from the test was relatively high, with a peak heat release of 990 kW being measured. The CO yield obtained were representative of well-ventilated flaming. The measurements taken in the exhaust duct were very dilute. This was the case for most of the gas measurements taken in the duct when compared to the door measurements.

Comparatively, the addition of a door to the test room did not force the fire to transition to under-ventilated flaming. Despite the restriction on the ventilation, the maximum equivalence ratio reached was only 0.95

When using 2x SBI rigs with no door, there was sufficient fuel for the fire to transition to under-ventilated flaming. The equivalence ratio was measured to be 1.5 at its peak, which is representative of under-ventilated conditions. However, the sampling did take place inside of the flame as the fire became so vigorous that the flames poured out of the test room for a significant portion of the test. This means that the equivalence ratio was 1.5 within the flame zone, and is less indicative of the actual fire condition in the room.

This research has provided the experimental methodologies to assess smoke toxicity at a range of ventilation conditions in an ISO 9705 test room. The equivalence ratios obtained were representative of well-ventilated and under-ventilated flaming and the transition point between the ventilation conditions ($\phi = 0.95$).

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