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THE INFLUENCE OF ENCLOSURE ON BURNING CHARACTERISTICS OF OSB FURNISHINGS

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ABSTRACT

This paper presents a series of full-scale tests conducted with office furniture made from OSB boards. Ignition source (30 kW gas burner) position and enclosure effects, free burn vs. ISO 9705 room, were evaluated from the perspective of instantaneous (HRR) and total heat (THR) released by the fuel packages. It was found that both of the evaluated factors have impact primarily on HRR – the peak ranging from 874 kW to 1 154 kW was delayed by approx. 50 to 60 s in the free-burn experiments; the THR remained relatively consistent at approx. 875 ± 30 MJ, meaning that in the observed period very similar amounts of fuel were burned. The thermal feedback within the enclosure seemed to be partially counteracted by the lack of oxygen, resulting in slightly higher HRR in free-burn test following the first peak. The findings of the research are applicable to fire hazard prediction by fire modelling.

KEYWORDS: OSB, thermal feedback, oxygen concentration, heat release rate, room corner test.

INTRODUCTION

Agglomerated wood, or sheet wood materials are extensively used in construction, furniture manufacture and many other industries. As per the Global forest products facts and figures report 2018 (2019) reconstituted panels (OSB, particle boards and fibreboards) dominate other product categories in Northern America and Europe. In addition, OSB and particle board had the fastest growth in production, increasing by 25% and 13% respectively over the period from 2014 to 2018. Most of this growth for both products occurred in Eastern Europe including the Russian Federation.

OSB (oriented strand board) boards are made from compressed-oriented wood strands in layers (usually 3) combined by adhesives. In Europe, the boards are mostly produced from pine and spruce, but for production is possible to use wood with density between 350-700 kg·m^{-2}. Individual strips of coniferous wood are about 0,4-0,8 mm × 6-25 mm × 75-130 mm. Longer strips are used for surface layers, smaller ones are in the middle of the board (Böhm et al. 2012). Their strength depends on used glue and thickness. Although the production companies in North America are still use PF adhesives in bigger share, PMDI, a mixture of monomeric diphenylmethane di-isocyanate and methylene-bridged oligo-aromatic isocyanates (Lay and Cranley 2003), is the primary adhesive system used in OSB production in Europe (Grunwald and Stroobants 2014, Grunwald 2014). Other types of glue used in production of OSB are urea formaldehyde (UF), melamine urea formaldehyde (MUF) of phenol-formaldehyde (PF). There are two standard formats of OSB boards sold in our region. The basic dimensions of the board with groove are 2 500 mm × 625 (675) mm. The dimensions of the plain-edge board are 2500 mm × 1250 mm. The thickness of OSB boards varies from 12 mm to 25 mm. They are divided into 4 types by their strength and moisture resistance (OSB-1 to OSB-4) according to EN 300 (2006).

Fire properties and hazards

The boards are usually classified according to EN 13501-1 to reaction-to-fire class D-s1,d0 (ČSN 73 0810 2016). This base classification is established in through the Classification without further testing (CWFT) principle. In case of OSB boards fulfilling EN 300 requirements, with a minimum density of 600 kg·m^{-3} and a minimum thickness of 15 mm, they may be classified as D-s2, d0 for applications excluding flooring and D_{FL}-s1 for flooring applications (Commision decision of 17 January 2003 establishing the classes of reaction-to-fire performance for certain construction products. Notified under document number C(2002) 4807 as amended). Further information on CWFT for wood-based products may be found in (Mikkola and Östman 2004, Östman and Mikkola 2006).

Since some applications require better fire performance, the market offers OSB boards with better reaction-to-fire classes, e.g. board called Kronospan OSB Firestop with reaction-to-fire class B-s1, d0.

To achieve better fire classification and improve fire performance of agglomerate wood products, various fire-retarding components are added to the binder and/or the outermost covering layers or protective films. Among recent research, Martinka et al. (2021) studied the effects of aluminium hydroxide; a comprehensive overview may be found in Aseeva et al. (2014).

Apart from construction material, OSB boards are also used to make furnishing. It is therefore necessary to understand fire hazards associated with such use. Important characteristics, from the fire-spread perspective, include the combination of critical heat flux and time to ignition. (Martinka et al. 2020) examined various OSB configurations and found the time to ignition to be as low as 19 s for the radiant heat flux of 19 kW·m^{-2} and the lowest critical heat flux to be below 10 kW·m^{-2}. Unlike massive wood elements (Dúbravská et al.

2020), sheet wood products, including OSB may be prone to twisting and bending particularly at lower thicknesses, leading to early disintegration of protective char layer.

When considering fire hazards in enclosures, it is important to be able to predict fire severity based on the limited experimental data available. Kadlic (2018) investigated various possibilities of prescribing burning fuel items and discussed differences in modelling results when free-burn and enclosure data were used. Wade (2019) proposed a mathematical approach to account for the enclosure effects on fuel packages and combustible constructions. This model accounts for thermal effects, vent mixing flow and oxygen concentration. Still, the appropriate experimental setup and data representation for fire modelling and engineering remain a significant question, as Babrauskas notes in (Hurley et al. 2016).

MATERIALS AND METHODS

The conducted full-scale fire tests are part of a complex research "Pyroboard" focusing on the computational modelling of pyrolysis and should serve for data validation. The main objective of the project is to describe the pyrolysis and burning of agglomerated wooden materials through a range of parameters collected by micro-, mid- and full-scale experimental research. This will allow proper mathematical modelling of wood burning.

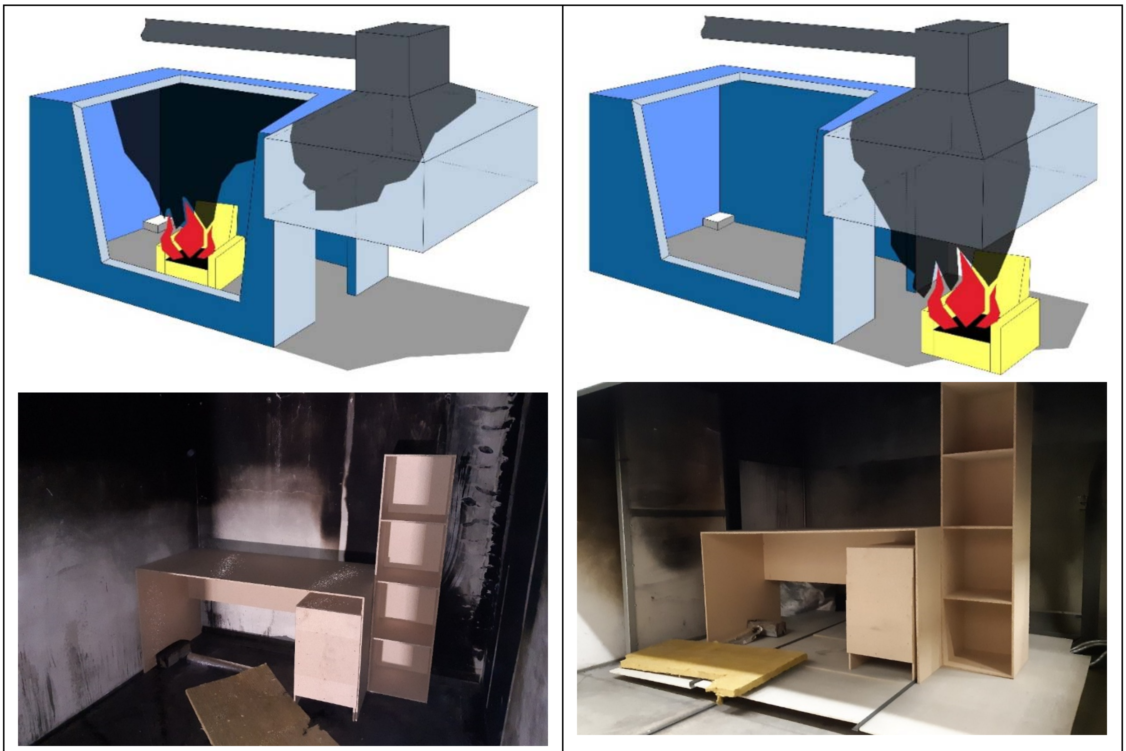
The test specimens are made from Oriented strand board (OSB) satisfying requirements of EN 300. Since the objective was to establish the properties for plain furniture, no further materials are included in fire tests. Test setup represents an office desk with drawers under the desk next to its right leg and a shelf cabinet on the right side of the desk: Office desk consists of desk 1 600 × 800 mm with two board legs 800 × 800 mm and board trestle 1600 × 400 mm. Chest of drawers 400 mm wide, 600 mm deep and 700 mm high with 4 openable drawers 150 mm high. Shelf cabinet 400 mm wide, 400 mm deep and 1 600 mm high with 4 uniform shelf spaces. For slight fire load decrease the OSB boards of thickness 12.5 mm were used. Selected properties of the OSB boards are summarized in Tab. 1.

Tab. 1: Selected properties of OSB boards used as fuel load.

Property	**Value**
Density	610.7 $kg \cdot m^{-3}$
Thermal conductivity at 20°C	0.19 ± 0.02 $W \cdot m^{-1} \cdot K^{-1}$
Specific heat (dry) at 20°C	1.18 $kJ \cdot kg^{-1} \cdot K^{-1}$

The boards were joined together mechanically with screws. Fire source that simulates fire of a trash bin is a gas burner put under the table. The heat output of the burner is constant 30 kW and the duration of the ignition period is 480 s (8 min). The whole process was done in the Fire laboratory of University centre of energy efficient building of Czech Technical University in Prague, where the Room corner test apparatus is installed. Room corner test (ISO 9705-1: 2016) consists of a small room (3.6 × 2.4 m and 2.4 m high) with one door opening and the exhaust hood 3.0 m × 3.0 m in front of the room. Exhaust fumes proceed to the analysers to obtain data of the heat release rate, so this apparatus can serve as a furniture calorimeter. Ventilation unit has maximal volume flow 3.5 $m^3 \cdot s^{-1}$ (approx. 13.000 m^3 per hour).

There were four constellations executed differing firstly in the test setup location itself where the smoke and temperature accumulation is crucial and secondly in location of the burner: *(1)* If the furniture is located inside the room, it represents single-person office where the effect of single burning item should be more noticeable while installation under the exhaust hood where the fumes go straight to the ventilation is similar to well-ventilated open spaces with larger area to heat up (Fig. 1). It is assumed the fire inside the single-person office is more intensive and faster. *(2)* The burner was put either to the left next to the left table leg or to the right side of the working space next to the drawer chest (Fig. 2). Various location was chosen just to see whether any difference of the heat release occurs.



Room corner test (RCT) setup.	Well-ventilated hood setup.

Fig. 1: Indicative display of test configurations.

As mentioned before, the ventilation of the space, or exhausting the heated fumes respectively, seems to be crucial and can affect the test result in several ways. It is needed to say that due to calculation processes any change of the volume flow during the test results in the change of HRR (measurement error about 5% or more when the test is over ventilated). Constant flow is therefore favoured. The question was nevertheless which flow. On the one hand, higher volume flow, especially in the ignition phases of the well-ventilated test, entrained the flame causing a significant delay of the flame spread. On the other hand, in HRR peak times the hood was not capable to exhaust all the smoke products. Finally, there needed to be separate types of ventilation scenarios for the room and well-ventilated test: the room test setup had constant volume flow 60% (around 2.0 $m^3 \cdot s^{-1}$), the well-ventilated test setup started at 30% (1.0 $m^3 \cdot s^{-1}$) and after 500 s, when the furniture was definitely ignited, the volume flow increased to 80% (2.8 $m^3 \cdot s^{-1}$). And there were situations when even such volume flow was not enough to exhaust all the fumes and had to be increased to 100%.

Fire experiment has no pre-set duration. Test started in T= 0 s with ventilation on according to the test setup and data collection, time step was set to t = 3 s. After 120 s, the gas burner was ignited (T = 120 s) and burned for 480 s (T = 600 s). Test procedure for both constellations can be found in Tab. 2.

Tab. 2: Timeline of the experiment.

Time (s)	Room corner test	Well-ventilated
0	test start, data collection extraction capacity @ 60%	test start, data collection extraction capacity @ 30%
120	burner 30 kW	burner 30 kW
500	—	extraction capacity @ 80%
600	burner off	burner off
Until burnout	Free burn	

Except the quantities characteristic for furniture calorimeter, such as heat release rate, smoke production rate or optical density, surface temperature at 10 points of the model furniture were collected (Fig. 2 and Tab. 3). Cable thermocouples type K, 2×0,5 mm^2 with mineral insulation were used. Tip of the thermocouples were shielded by 3 mm thick mineral fibre board. In this article, only thermocouples T02 a T03 will be discussed.

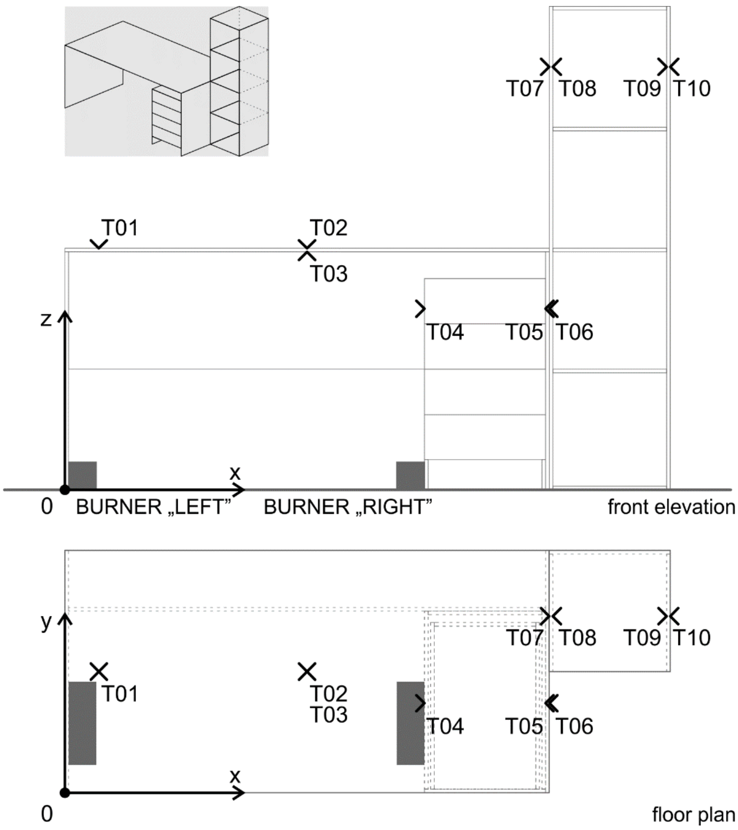


Fig. 2: Test setup with thermocouples location.

Tab. 3: Thermocouples T02 a T03 locations.

Txx	Location	x (mm)	y (mm)	z (mm)
02	On the upper side of the table desk	800	400	800
03	On the bottom side of the table desk	800	400	788

RESULTS AND DISCUSSION

The results from the first series of test burns conducted inside the ISO 9705 room are shown in Fig. 3. The results were shifted back by 120 s to discount the pre-burn period when the gas burner (ignition source) was off. After an initial delay of approximately 100 s there is a growth period until the first peak. The maximum HRR values reached for this scenario were 1132 kW (at 524 s) for ignition on the left side and 874 kW (at 510 s) for ignition on the right side.

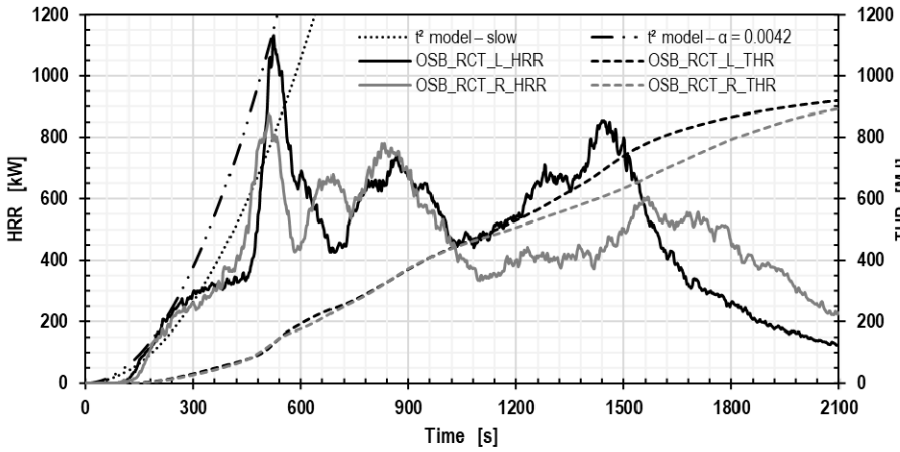


Fig. 3: Room corner test results for office furniture made from OSB; dotted line represents a t^2-model fit with α = 0.00293 kW·s^{-2} (slow) and α = 0.0042 kW·s^{-2} (custom).

The results from the second series of test burns conducted as free-burn tests under the hood are shown in Fig. 4. The results were again shifted back by 120 s to discount the period when the gas burner (ignition source) was off. After an initial delay of approximately 100 s there is a growth period until the first peak. Until approx. 600 s, the growth is relatively slow, followed by a steeper growth period for the next 50 - 100 s until the first peak is reached. This peak is associated with the fire spread under the desktop and rapid release of flammable pyrolysis gases from its surface as it is heated underneath. The subsequent development of fire and HRR is driven by progressive collapse of the furniture. The second prominent peak in the RCT_L scenario is caused by fire development on the shelves side. When fire was initiated on the right side (RCT_R) the peak is not as prominent.

Similar trends in HRR and the overall development of fire was observed in tests conducted in well-ventilated conditions under the hood, see Fig. 4. Due to the lack of thermal feedback, the effect of the enclosure, the development phase is prolonged, nonetheless after reaching approx. 375 - 400 kW there is a steep increase in HRR until the first peak is reached. There is also a difference in the peak HRR between the burner locations, left and right, however a less significant one.

The first peak HRR occurs approx. 30 s after the burner is turned off in the tests conducted inside the RCT and approx. 90 s in the free-burn tests. The contribution of the burner is subtracted from the analysed HRRs, i.e. the values presented in Figs. 3 and 4 represent net heat release of the OSB furnishings. The burner flames contribute to the initial flame spread on the OSB surfaces, however, it was not possible to quantify this effect. It is expected that shorter duration of ignition period would delay the onset of exponential growth period described below.

An overview of the main fire severity parameters is provided in Tab. 4. It may also be seen, that the total released amount of heat does not differ significantly. Over the considered period of 2 100 s (35 min), the difference between the maximum and minimum THR is 61 MJ, which is approximately 3.6 kg of fuel, assuming $h_{c,eff}$ = 17 MJ·kg^{-1}. This is less than 10% if the minimum THR is considered a baseline.

The first difference that is apparent when comparing HRR shown in Figs. 3 and 4 is the prolonged fire growth stage up until approx. 400 kW. The fire growth until 400 kW takes about 100 - 150 s longer in tests under the hood. It is likely due to the lack of thermal feedback, since the heat in the fire and smoke plume is extracted rapidly, hence, the smoke layer cannot form fully and there is no construction to re-radiate heat back to the fuel. Since the heat is contained better in the RCT tests, the surfaces of the furniture heat up more rapidly, aiding the flame spread.

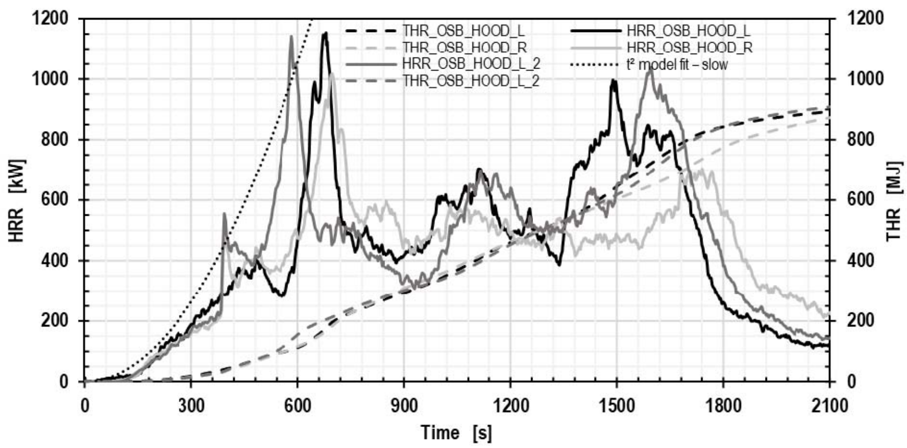


Fig. 4: Free-burn test results for office furniture made from OSB; dotted line represents a t^2-model fit with α = 0.00293 kW·s^{-2} (slow).

Tab. 4: Overview of the main parameters of the burn tests.

Value	RCT_L	RCT_R	HOOD_R	HOOD_L	HOOD_L_2
Peak HRR (kW)	1 132	874	1 017	1 154	1 143
Time to peak (s)	524	510	580	560	583
Time to 1MW (s)	510	—	577	547	579
THR (MJ) (0–2100 s)	902	861	841	878	889

The above assumption is also supported by the temperature development on the top and bottom surfaces of the desktop (Fig. 5). It may be seen that there are significant temperature differences in the temperatures on the bottom side of the desktop. These are likely caused by the significant airflow for scenarios where the burning furniture is placed directly under the extraction hood – well-ventilated free burn experiments (HOOD). This airflow affects the heat transfer patterns under the desk and since approx. 70 - 75% of the produced heat is transferred through convection in the fire and smoke plume (Heskestad and Delichatsios 1989, Karlsson and Quintiere 2002).

Hence the combined effect of reduced thermal feedback and increased heat removal in the free burn experiments, appears to cause slower fire growth and delays the first peak. Due to very transient nature of the flow patterns (even between the experiments in the same configuration) it is, however, difficult to quantify these effects precisely. The steep increase in HRR seems to corelate with the charring temperature of wood ≈ 300°C – for RCT scenario at approx. 480 s and for HOOD scenarios 560 s and 620 s, respectively. It must be noted, however, that there are multiple other factors affecting the growth phase, e.g. structural deterioration, which are difficult to quantify. The greater peak (1 132 kW) for the configuration with the burner on the left side may be attributed to the position of the desk – the left side is in the corner of the room, i.e. the flames are enclosed on two sides, so more heat is directed at the desk.

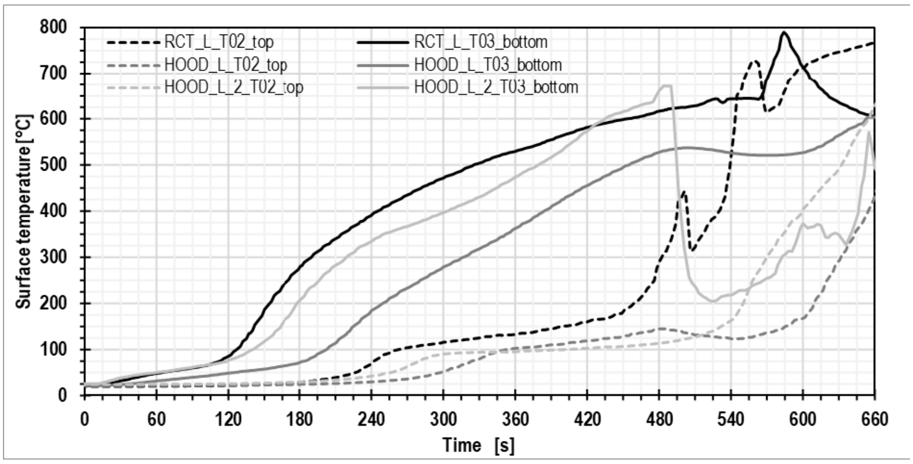


Fig. 5: Temperatures at top and bottom surfaces in the centre the desktop.

Fire growth phase is an important characteristic from the fire safety engineering perspective. It may be approximated as an exponential function, t^2 model, which follows (Heskestad and Delichatsios 1979):

$$\dot{Q} = \alpha \cdot t^2 \tag{1}$$

where: $\dot{Q}$ – heat release rate (HRR) (kW), α – fire growth rate coefficient (kW·s^{-2}), t – time (s).

There are four standardised fire growth rate coefficients (NFPA 72 2017): slow 0.00293 kW·s^{-2}, medium 0.01172 kW·s^{-2}, fast 0.0469 kW·s^{-2}, and ultrafast 0.1876 kW·s^{-2}.

These fire growth rate coefficient are characteristics of various products and occupancies (PD 7974-1 2003, Mayfield and Hopkin 2011, BS 9999 2017).

The t^2 fire growth model was fitted to the experimental data. From the standardised fire growth rate coefficients, $\alpha = 0.00293$ kW·s^{-2} (slow) follows the development stage the closest, dotted lines in Figs. 3 and 4. In the case of the RCT tests, the value of α was increased to 0.0042 kW·s^{-2}, since the time to reach the peak HRR was underestimated. As indicated in Fig. 3, the custom fire growth curve is still relatively close to the slow fire growth curve (about ¼ of the slow→medium band). Overall, the experiments indicate that there is a relatively slow fire growth stage for this type of furniture and initiation source.

Mayfield and Hopkin (2011) fitted the t^2 fire growth model to a well-ventilated free-burn experiment with an office furniture setup, and they found the fire growth phase also to be rather slow. In fact, for the investigated period $500 < t \leq 1200$ s, they derived $\alpha = 0.0003$ kW·s^{-2}, which is an order of magnitude lower than for the slow fire growth rate. For an unsprinklered reception area they derived $\alpha = 0.003$ kW·s^{-2} for the investigated period $180 < t \leq 1400$ s, which may be considered almost equal to the slow fire growth rate ($\alpha = 0.00293$ kW·s^{-2}). Although, there were other fuel items present, in the above experiments, primary fuel load consisted of an office desk with a chest of draws and shelving units.

Similar results for office furniture were recorded by (Walton and Budnick 1988). Again, significant variations were present, particularly between free burn and enclosure experiments. In free burn experiments the fire growth was found to be within the slow–medium zone.

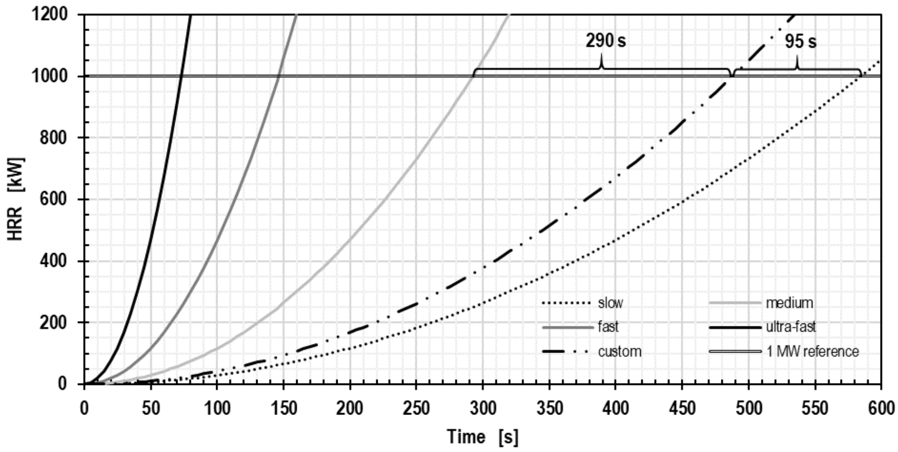


Fig. 6: Comparison of fire growth rates; custom – $\alpha = 0.0042$ kW·s^{-2}.

As regards the overall fire severity, there is no clear trend. HRR and THR curves in Figs. 3 and 4 indicate somewhat less severe course of fire for scenarios in which the burner was on the right side, both in the enclosure as well as freeburn. The decay phase, however, compensates for this (longer and/or higher HRR) to a certain extent. There are competing effects of heat balance (thermal feedback and gas extraction) and oxygen availability. For enclosure tests thermal feedback is expected to be more prominent and less heat is directly extracted due to the airflow affecting directly on the fire zone. The reduced airflow also means reduced oxygen concentration, which in turn reduces the burning and heat release rate. On the contrary there is sufficient oxygen available in the free burn experiments, however, more heat is lost due to the increased airflow and absence of established hot layer and deflected flames.

There are also limitations as to what is the extent of HRR enhancement by thermal feedback within the enclosure. Babrauskas (Hurley et al. 2016) discusses various aspects affecting thermal feedback and states, that there is approx. 20% enhancement possible for fires in the 100 - 1000 kW range. The effect is also dependent on the proportion of fuel surface able to “see” radiating surfaces, gases, and flames. Since, the tested fuel packages had large surfaces facing “inside”, e.g. shelve compartments, desk underside, drawers, etc., thermal feedback enhancement of heat release rate is expected to be limited. As Pokorny and Malerova (2017) and Pokorny and Gondek (2016) note, the fire location (corner, wall and free standing) and ventilation conditions have a significant impact too, which is in line with the findings summarised in (Wade 2019).

CONCLUSIONS

As part of a greater research project, this paper discusses the differences in fire behaviour of office furniture made from OSB boards when located inside an enclosure and directly under an extraction hood (free-burn). The test enclosure and extraction system are as per the room corner test (RCT), specified by ISO 9705.

After piloted ignition (30 kW burner) the development of fire was observed with the objective to identify them main factors causing the differences. The purpose for this comparison was the accuracy and mutual replaceability of enclosure and free-burn test results. Very often such results are applied as design fire in fire engineering, which may lead to under or overestimation of fire hazards. The investigated furniture set-up comprising a desk, chest of drawers and a shelving unit is typical for an office occupancy or home workstation. Differences were found both due to the location of the burner (ignition source) as well as burning environment – enclosed vs. free-burn. Although the total heat released remained relatively consistent, THR ≈ 875 ± 30 MJ.

The instantaneous heat release rate, however, shows significant variability for both ignition and enclosure conditions. The first HRR peak is delayed by about 50 - 60 s for free-burn conditions. On the other hand, despite faster peak onset, the following HRR appears to be less severe for RCT (enclosed) tests. In case right side ignition (chest of drawers), the peak HRR does not even reach 1 MW. It appears, that the thermal feedback effect enhancing the burning rate is limited due to the geometry of the fuel (significant internal surfaces) and the oxygen-deprived atmosphere inside the enclosure hampers fire development and burning rate. As regards applicability to fire modelling for fire hazard predictions, the data obtained provide a useful insight on the variability associated with more complex geometries of solid fuel packages. Although there are options to model burning rate enhancement in various fire models (B-Risk, FDS) one should be careful not to over- or underpredict fire severity. In particular, zone models offer only a limited capability for fuel geometry representation (2D and 3D simple rectangular shapes) and the burning rate enhancement models are sensitive particularly to the amount and orientation of surface exposed to radiating heat.

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