FIRE AND MATERIALS ’98

5th International Conference

February 1998
San Antonio Tx, USA

White, R. H.; M.A. Dietenberger; and H. Tran. 1998. Comparison of test protocols for standard room/corner tests. p. 77–88. *In:* Proceedings of the Fire and Materials ’98 Conference. 23–24 Feburary 1998. San Antonio, TX. Interscience Communications Ltd., London.

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COMPARISON OF TEST PROTOCOLS FOR STANDARD ROOM/CORNER TESTS

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ABSTRACT

As part of international efforts to evaluate alternative reaction-to-fire tests, several series of room/comer tests have been conducted. This paper reviews the overall results of related projects in which different test protocols for standard room/corner tests were used. Differences in the test protocols involved two options for the ignition burner scenario and whether the ceiling was also lined with the test materials. The test materials were placed on three walls of the room in all the tests. The two burner scenarios were (1) 40 kW for 300 s followed by 160 kW for 300 s and (2) 100 kW for 600 s and 300 kW for 600 s. Materials tested were mostly different wood products but included gypsum board and a few foam plastics. The 40- and 160-kW burner scenario without the ceiling lined does not provide a severe enough test for fire-retardant-treated materials. Use of the 100- and 300-kW burner scenario without lining the ceiling provided the ability to differentiate wood products with flame spread indexes of 70 to 125 from those with higher flame spread indexes. Lining the ceiling with the test material provides for a more severe test.

INTRODUCTION

The standard room/corner test is the fill-scale reaction-to-fro test for evaluating building materials. It is not only used to evaluate building materials but is often used as the basis for evaluating the validity of bench-scale reaction-to-fire tests. The ISO standard[1] provides for alternatives with respect to the burner scenario and whether the ceiling is also lined with the test material. The room/corner tests reported in this paper were largely part of international efforts to evaluate alternative reaction-to-fire tests. Materials tested were mostly wood products but included gypsum board and a few foam plastics. The tests were conducted either at the USDA, Forest Service, Forest Products Laboratory (FPL) in Madison, WI, USA, or at the National Research Council of

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Canada (NRCC) at Ottawa, Ontario, Canada. Tests at FPL were conducted in cooperation with the State Forest Products Research Institute of Slovakia (SDVU). The test materials were largely provided by Forintek Canada Corp. and American Forest & Paper Association (AF&PA). Selected tests of the American Society for Testing and Materials (ASTM) interlaboratory evaluation of a proposed ASTM test protocol are also included. In addition to the room/comer tests, most of the materials were also tested in the cone calorimeter. However, this paper is limited to the room/corner tests with emphasis on the flashover times for the different protocols. This paper reviews the overall results of these related projects and compares the different protocols.

METHODS

The tests were conducted according to ISO Standard 9705[1] and the proposed ASTM standard. The proposed ASTM protocol was published as a proposed standard in 1982 and used for the ASTM Institute for Standards Research (ISR) interlaboratory test program[3]. The standard room/corner test involves a propane burner in the comer of a room that is 3.6 m long, 2.4 m wide, and 2.4 m high. The room has a single door for ventilation in the center of one 2.4- by 2.4-m end wall.

In this series of tests, we investigated two differences in the test protocols, the two options for the ignition burner scenario and whether or not the ceiling was also lined with the test materials. The two burner scenarios were (1) 40 kW for 300s followed by a change to 160 kW for 300s (ASTM option) and (2) 100 kW for 600s followed by a change to 300 kW for 600s (ISO option).

Burner Scenario 1 was the primary protocol for the proposed ASTM procedure. The ISO 9705 standard specifies an additional 600 s for the 160-kW burner after 300 s of 40 kW as an alternative ignition program. Scenario 2 is the primary option in the ISO room/corner test standard. In addition to the kilowatt settings, the ASTM and ISO test protocols also each specify a different size burner. In all the NRCC tests, the 305- by 305-mm burner of the ASTM protocol was used. In the FPL tests, the ASTM burner was used for Scenario 1 tests and the 170- by 170-mm burner of ISO 9705 was used for the Scenario 2 tests. In NRCC tests without flashover, the tests were terminated at 900s.

The second difference in the test protocols was whether or not the ceiling was also lined with the test materials. In Europe, room/corner tests have generally been conducted with the ISO primary method, which is the ISO burner and the test material on the ceiling. In the United States, the ASTM protocol called for the ASTM burner and no test material on the ceiling. The test materials were placed on three walls of the room in all the tests. No test material is placed on the fourth wall, which has the door opening. In tests with no test materials on the ceiling, the ceiling was lined with gypsum board.

In the Slovakia-U.S. project[4], the room/corner test protocol was a combination of the European and U.S. methods, namely the ISO burner but no test material on the ceiling. The Forintek-NRCC project[5,6] was largely a comparison of the ISO and ASTM test protocol but included some tests of all four variations. Many of the wood products tested in the Slovakia project had previously been tested by FPL using the ASTM protocol[7] or by laboratories in the ASTM ISR interlaboratory test program[3].

In the standard test, the exhaust from the room is collected via a hood and the heat release rate is determined using the oxygen consumption methodology. Visual observations are made of flame spread and the times that flames are observed emerging beyond the doorway. A heat flux meter is located at the geometric center of the floor.

The times for flashover can be determined by a number of different criteria. In this paper, two criteria are used, the visual observation of flames emerging out the door and a heat flux of 20 kW/m^2 to the floor.

MATERIALS

A total of 24 materials was used in the different test series. These materials included gypsum board four fire-retardant-mated (FRT) plywood products, two polyurethane foam plastics, an expanded polystyrene foam plastic, four particleboard, two Douglas-fir plywoods, and ten additional untreated wood products (Table l). Designations F, M, N, N1, N2, and R were used to differentiate between similar materials based on the source of the materials. The symbols represent Forintek Material bank of wood products for fire research belonging to AF&Pa NRCC, and Round robin materials (ASTM ISR interlaboratory evaluation). The material ID numbers listed in the tables are used to identify the materials in the figures

Table 1. List of materials evaluated in the room corner test.

Material ID number	Material	Thickness, mm	Density, kg/m^3
1	Gypsum board	13	755
2	FRT plywood N	13	
3	FRT Plywood M	13	653
4	FRT plywood F	13	600
5	FRT plywood R	13	560
6	Polyurethane foam N	40	
7	Polyurethane foam R	23	29
8	Expanded polystyrene foam	50	29
9	White spruce lumber	19	361
10	Redwood lumber	19	420
11	Red oak lumber	19	624
12	Southern Pine lumber	19	593
13	Spruce plywood	13	
14	Douglas-fir plywood M	13	515
15	Douglas-fir plywood R	13	540
16	Southern Pine plywood	13	605
17	Oak-veneered plywood	13	480
18	Particleboard M	13	790
19	Particleboard N1	13	
20	Paticleboard N2	13	
21	Hardboard	6	1025
22	Hardboard, imitation stucco coating	10	930
23	Oriented strandboard	13	645
24	Waferboard	13	620

RESULTS

Tables 2 to 7 show each test series. Table 2 is the initial FPL test series using the 40- and 160-kW burner protocol with the test material on the walls[7]. Table 3 lists the average results for three of the materials tested as part of the ASTM ISR interlaboratory test program[3]. These three materials were later tested using the 100- and 300-kW protocol. The average ASTM E84 flame spread index[8] (FSI) for the three materials is also included in Table 3. Table 4 lists the results for the initial NRCC series, which involves all four variations of the burner-ceiling lining protocols Results for a second series at NRCC are listed in Table 5[6]. These tests were limited to the primary ASTM and the primary ISO test protocols. Table 6 shows the FPL-SDVU results using the 100- and 300-kW burner scenario and the ceilings not lined. Initial results were previously reported[4]. The ASTM E 84 flame spread index values listed in Tables 6 and 7 are estimated values from the published literature and Table 2. Table 7 shows additional tests from an FPL-Forintek Corp. cooperative effort.

Table 2. FPL–AF&PA room/corner tests using 40- and 160-kW burner and test materials on walls only[7].

Materials	Material ID no.	Times for flashover, s		FPL test no.
		Flames out door	20 kW/m^2 to floor	
Gypsum board	1	NFO[a]	NFO[a]	2
FRT plywood M	3	NFO[a]	NFO[a]	36
Redwood lumber	10	378	378	32
Douglas-fir plywood M	14	380	378	5
Southern Pine plywood	16	344	348	33
Particleboard M	18	336	342	34
Oriented strandboard	23	266	270	35

[a] Test terminated at 600 s without flashover.

Table 3. ASTM ISR room/corner tests using 40- and 160-kW burner and test materials on walls only[3].

Materials	Material ID no.	Number of tests	Mean times for flashover, 20 kW/m^2 to floor, s	ASTM E 84 flame spread index[8]
FRT plywood R	5	5	NFO[a]	17.0
Polyurethane foam R	7	6	358	23.9
Douglas-fir plywood R	15	10	391	91.2

[a] Test terminated at 600 s without flashover.

Table 4. NRCC room/corner tests using different test protocols[5].

Materials	Material ID no.	Times for flashover, s			
		40/160 kW, ceiling unlined	40/160 kW, ceiling lined	100/300 kW, ceiling unlined	100/300 kW, ceiling lined
		20 kW/m^2 to floor			
FRT plywood N	2	NFO[a]	740	NFO[a]	640
Polyurethane foam N	6	NFO[a]	320	690	50
Particleboard N2	20	335	275	230	140
		Flames out door			
FRT plywood N	2	NFO[a]	NFO[a]	NFO[a]	640
Polyurethane foam N	6	NFO[a]	330	NFO[a]	63
Particleboard N2	20	325	240	230	140

[a] Test terminated at 900 s without flashover.

Table 5. NRCC–Forintek room/corner tests using different test protocols[6].

Material	Material ID no.	Times for flashover, flames out door, s	
		40/160 kW, ceiling unlined	100/300 kW, ceiling lined
FRT plywood F	4	NFO[a]	NFO[b]
Expanded polystyrene	8	174	36
Spruce plywood	13	372	186
Oak-veneered plywood F	17	330	78
Particleboard N1	19	306	156
Hardboard, imitation stucco coating	22	324	174

[a] Test terminated at 900 s without flashover.

[b] Test terminated at 840 s. Floor heat flux exceeded 20 kW/m^2 during a "steady" combustion period between 600 s and termination of test that never resulted in steady flaming out of the doorway. Heat release rate exceeded 1000 kW at about 735 s.

Table 6. FPL–SDVU room/corner tests using 100- and 300-kW burner and test materials on walls only.

Materials	Material ID no.	Times for flashover, s		Estimated ASTM E 84 flame spread index	FPL test no.
		Flames out door	20 kW/m^2 to floor		
Gypsum board	1	NFO[b]	NFO[b]	10	49, 55
FRT plywood M	3	870[a]	882[a]	-	56
FRT plywood F	4	870	873	-	52
FRT plywood R	5	894	849	17	50
Polyurethane foam R	7	618	621	24	54
White spruce lumber	9	594	594	65	64
Redwood lumber	10	519	498	70	62
Southern Pine lumber	12	243	240	160	65
Douglas-fir plywood M	14	520	531	-	57
Douglas-fir plywood R	15	465	474	91	53
Southern Pine plywood	16	324	321	120	58
Oak-veneered plywood F	17	174	174	-	51
Particleboard M	18	241	237	150	59
Hardboard	21	227	222	185	61
Oriented strandboard	23	189	186	175	60
Waferboard	24	150	141	-	66

[a] Actual test involved only 300 s of 100-kW burner exposure prior to increase to 300 kW. Thus, 300 s was added to actual flashover times to obtain these values.

[b] Test terminated at 1200 s without flashover.

Table 7. FPL–Forintek room/corner tests.

Materials	Material ID no.	Test protocol	Times for flashover, s		FPL test no.
			Flames out door	20 kW/m^2 to floor	
FRT plywood M	3	100/300-kW burner, ceiling lined	636	633	67
Red oak flooring	11	100/300-kW burner, ceiling unlined	324	318	68
Red oak flooring	11	40/160-kW burner, ceiling unlined	366	369	69

DISCUSSION

The differences in the test protocols affect the sensitivity of the room/corner test to differences in the fire performance of the materials being tested (Fig. 1-4). The products listed in Table 1 are grouped in the order of gypsum board, FRT plywoods, foam plastics, sawn lumber, plywood products, and untreated composite wood products. This order is approximately in order of increasing ASTM E84 FSI. In the following discussion we review the results for each of the four protocols.

With the 40- and 160-kW burner program and the unlined ceiling protocol, flashover occurred shortly after the increase to 160 kW for almost all untreated wood products (Fig. 1). Only one untreated wood product resulted in flashover during the initial 300 s of the 40-kW burner. Using the ASTM protocol, Gardner and Thomson[9] found that even sawn Blackbutt, which has a FSI equal to 48, had a flashover time of only 432 s. It appears that flashover times with this protocol cannot be used to distinguish materials that are Class II (26 to 75) in the ASTM E 84 test. There was no flashover with gypsum board, the FRT plywood products, and one of the treated polyurethane foam plastics. These materials have flame spread indexes of 25 or less.

The data for the 40- and 160-kW burner program and the test materials on the ceiling and walls are very limited (Table 4 and Fig. 2). By adding the test material to the ceiling, the particleboard had flashover prior to the change to the 160-kW burner setting. In addition, FRT plywood N and treated

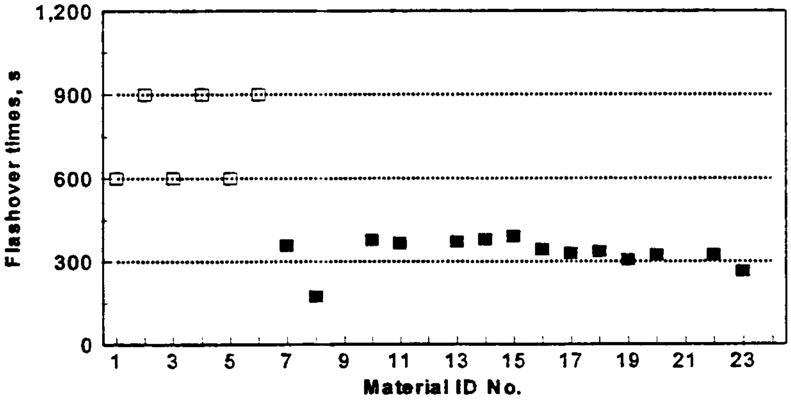

Figure 1. Flashover times for the different materials tested with the 40- and 160-kW burner program and no test material on the ceiling. The material ID numbers are listed in Table 1. Open symbols indicate termination of test without flashover.

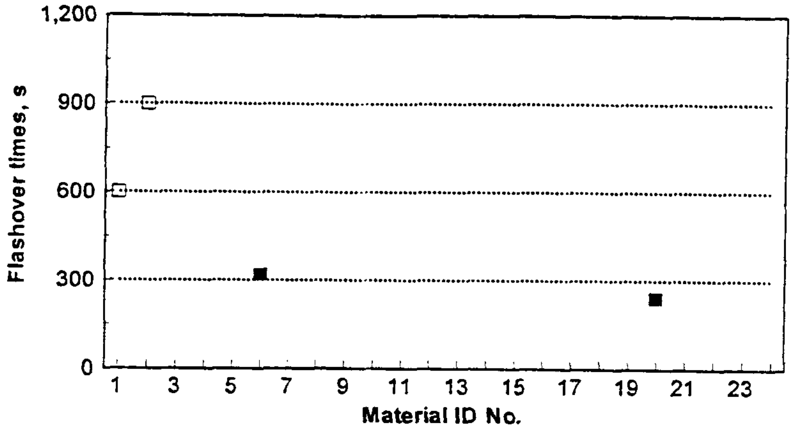

Figure 2. Flashover times for the different materials tested with the 40- and 160-kW burner program and with the test material on both the walls and the ceiling. Material ID numbers are listed in Table 1. Open symbols indicate termination of test without flashover.

polyurethane foam insulation N resulted in flashover with the test material on the ceiling (Fig. 2). When tested without the ceiling lined, these two materials did not flashover with the 40- and 160-kW burner program.

With the 100- and 300-kW burner program and unlined ceiling, flashovers occurred during the entire 600 s of the 100-kW burner (Fig. 3). Materials 9 to 12 are different species of sawn lumber, and 13 to 17 are the untreated plywood products. Six of the untreated wood products resulted in flashover in a narrow range of 174 to 240 s. Flashover with the waferboard occurred in 141 s. Five untreated wood products had times that ranged from 318 to 498 s. All of these flashover times for untreated wood products occurred before the step increase of the burner to 300 kW. With the treated plywood and treated polyurethane foam plastics, flashover only occurred with the change to the 300-kW burner. In one test with a FRT plywood and in the test with gypsum board, no flashover occurred before termination of the test.

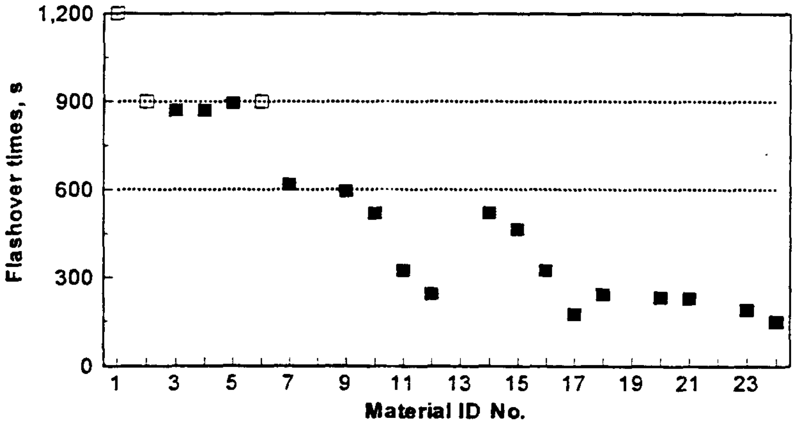

Figure 3. Flashover times for the different materials tested with the 100- and 300-kW burner program and with no test material on ceiling. Material ID numbers are listed in Table I. Open symbols indicate termination of test without flashover.

When the 100- and 300-kW burner program was used with the test material on the ceiling as well as the walls, there were large reductions in the flashover times (Fig. 4). This was particularly the case with the polyurethane foam plastic N, which had a flashover time of 50 s with the ceiling lined compared with 690 s without the ceiling lined. With the ceiling lined, two of the three FRT plywood products tested with this protocol resulted in flashover shortly after the increase to the 300-kW burner setting (636 and 640 s) compared with times close to or exceeding 900 s (873, 882 s, and no flashover at 900 s) when the ceiling was not lined. European results for FRT wood products on the ceiling were either no flashover or flashover shortly after the change to the 300-kW burner[10,11] level. In a report on 28 different materials [10], only one material resulted in flashover between 200 s and the change to the 300-kW burner level at 600 s. A melamine-faced particleboard had a flashover time of 465 s. Our results for 100 and 300 kW and ceiling lined are in agreement with other results of 131 to 157 s for untreated wood products[10,11]. In tests of particleboard with the 100- and 300 kW burner program[11] flashover occurred at 150 s with both walls and ceiling lined, 248 s with walls only, and 835 s with only the ceiling lined.

Effect of the burner size and burner program has been investigated[12,13]. Ahonen and others[14] conducted nine tests with three sizes of the burner (500, 300, and 170 mm) and three burner outputs (40, 160, and 300 kW)[12]. The size of the burner had little effect at 160 and 300 kW. At 40 kW, flashover times for the 500-mm burner were significantly greater than for the other two burner sizes. In our tests of particleboard on walls only, we obtained similar flashover times with the 305-by 305-mm burner and with the 170-by 170-mm burner (230s vs. 237s; Tables 2 and 5).

In this series of tests, only two burner scenarios were used. In the tests mentioned above, Ahonen and others[14] found that increasing the burner output from 40 to 160 kW reduced the flashover times for the particleboard on walls and ceiling from about 220 s to about 100 s but a further increase to 300 kW only decreased the flashover times to about 70 s[12]. In a few of our tests, flashover occurred without a change in the burner output. In our tests with particleboard on walls and ceiling, flashover times were 240 s with the 40-kW burner and 140 s and 156 s with the 100-kW burner (Tables 4 and 5). In the tests of oriented strandboard on walls only, flashover occurred at 266 s with the 40-kW burner and 189s with the 100-kW burner. In earlier tests, the effect of different burner programs was conducted with Douglas-fir plywood on the walls only (Table 8)[13]. The ceiling was lined with ceramic fiber insulation. The above results are shown in Figure 5. The results for Douglas-fir (Table 8) are shown in Figure 5 as the duration of exposure needed for flashover for the different burner

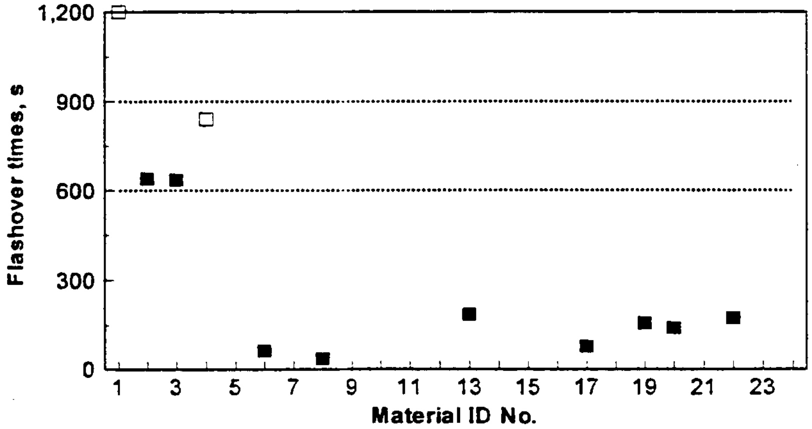

Figure 4. Flashover times for the different materials tested with the 100- and 300-kW burner program and with the test material on the walls and the ceiling. Material ID numbers are listed in Table 1. Open symbols indicate termination of test without flashover.

Table 8. Douglas-fir plywood tests with different burner scenarios[13].

Burner program	Times for flashover		Test no.
	Flames out door, s	20 kW/m^2 to floor, s	
15 min of 40 kW	604	606	18
5 min of 40 kW then 5 min of 160 kW	335	330	19
30 s of 40 kW, 30 s of 80 kW, 30 s of 120 kW, then 8 min of 160 kW	123	120	20
5 min of 40 kW, 5 min of 100 kW, then 5 min of 160 kW	370	366	26

settings when there was an initial 300 s exposure to the 40-kW burner. The curvilinear nature of the data in Figure 5 indicates that there are upper limits for burner settings that will result in further significant reductions in the flashover times for untreated wood products. The data suggest upper limits of 160 kW for a single initial burner setting and 100 kW for a subsequent burner setting after a lower initial exposure.

The selection of which protocol to use depends on the intended purpose. The 40- and 160-kW burner with ceiling unlined resulted in little differences between the different untreated wood products and a clear distinction for treated products in that there was no flashover for those products. By adding the test material to the ceiling, both the FRT plywood and the polyurethane foam plastic resulted in flashover before the end of the test. It is also more likely that materials with low ignition characteristics will flashover during the initial 40-kW exposure with the test material also on the ceiling. In contrast with the 40- and 160-kW scenario (Fig. 1), the use of the 100- and 300-kW scenario and the ceiling unlined (Fig. 3) provided the ability to differentiate those untreated wood products that have FSIS of 70 to 125 from those with higher FSIs (Fig. 6). The protocol with the 100- and 300-kW burner program with the ceiling unlined produced results that were consistent with expected performance in the ASTM E 84 flame spread test currently used to regulate surface flammability in the United States and Canada (Fig. 6). The flame spread values used in Figure 6 are mostly estimates based on the published literature for the generic wood products. By adding the test material to the ceilig, one appears to lose the ability to differentiate these wood products but gains a

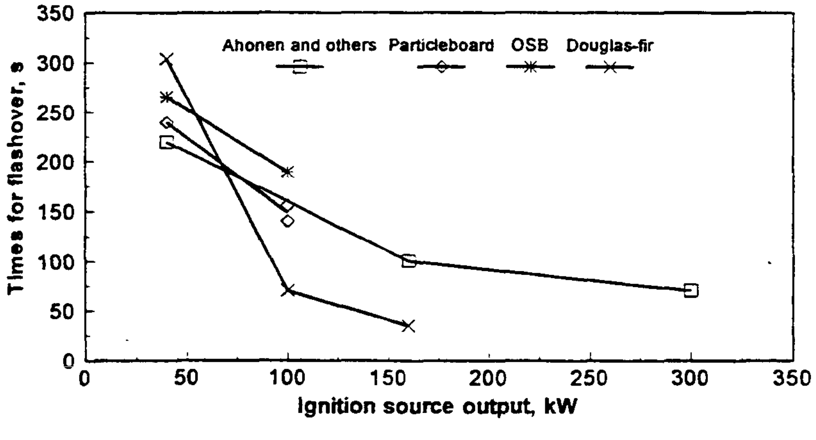

Figure 5. Effect of changes in the burner output on the flashover times. There was a 300-s preheating using a 40-kW burner in the Douglas-fir tests. Other tests are for a single constant burner only.

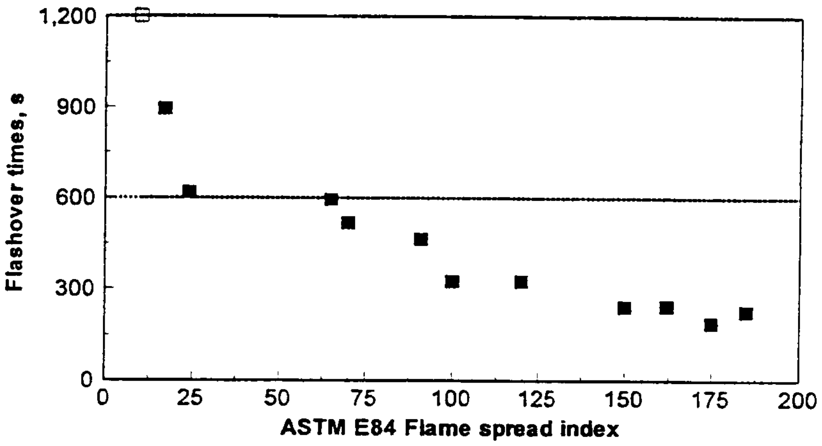

Figure 6. Comparison of the times flashover using the 100- and 300-kW burner program with the ceiling unlined with estimates for the ASTME flame spread index.

more definite distinction between groups of materials. For materials that flashover during the 100-kW exposure, flashover occurred in the first 300 s when the ceiling was also lined with the test material. Thus, the subsequent 300s of 100-kW exposure, a time period when few materials result in flashover, provides a clear dividing line between classes of materials. In the one FPL test with FRT plywood in which the initial exposure was mistakenly set at 300 s (FPL Test 56), the flashover times were identical to that for the 600-s exposure to 100 kW of the other two FRT plywoods (FPL Tests 50 and 53) except for the additional 300s. With the test material on the ceiling and the 100- and 300-kW burner program, one probably gains a more severe test of materials with very low flammability.

A number of different criteria have been used to determine the times for flashover. In this paper, we reported data for flames out the door and heat flux of 20 kW/m^2 to the floor. In Europe, the criterion of a 1000-kW heat release rate (including burner) is commonly used. Other criteria include ignition of paper bundles on the floor, average ceiling temperature of 600 °C, and doorway temperature of 600 °C. In tests of untreated wood products, we found agreement between the flames out the door and 20 kW/m^2 to the floor. With the FRT wood products and the treated polyurethane plastics, there were some inconsistencies in the results depending on the flashover criteria. In tests of the polyurethane foam N, the criteria of ceiling temperature of 600°C, floor heat flux of 20 kW/m^2, and paper ignition were satisfied but there was no apparent flame extension out the doorway nor a 1000-kW heat release rate. Similar results were obtained with FRT plywood N in which the 600°C ceiling temperature, 1000-kW heat release rate, and paper ignition were satisfied but flames out the door or 20 kW/m^2 to the floor did not occur. In the 100- and 300-kW, ceiling-lined test of FRT plywood F, the heat release rate increased quickly to about 800 kW after the burner increased to 300 kW but remained steady at this level until the test was terminated at 840s. The heat flux to floor exceeded 20 kW/m^2 but steady flames out the door were not apparent. In the 100- and 300-kW ceiling unlined test of FRT plywood M, the 20-kW/m^2 criterion was first exceeded at 640 s while flames out the door, 1000-kW heat release rate, and the second occurrence of the 20-kW/m^2 to floor occurred later at about 880 s. In the 100- and 300-kW ceiling unlined test of FRT plywood F, the 20-kW/m^2 to floor and the 1000-kW heat release rate were initially exceeded shortly after the change to the 300-kW burner but then decreased until increasing later when flames extended out the door at 870 s. Criteria such as those based on heat release rate, heat flux to floor, and temperature are more objective compared with the subjective visual observation of flames out the door, but they can provide misleading times if used alone.

CONCLUSIONS

Results in the room/corner test depend on the burner scenario and whether or not the ceiling is lined with the test material. The 40- and 160-kW burner without the ceiling lined did not provide a severe enough test to cause flashover with FRT materials. Use of the 100- and 300-kW burner program without lining the ceiling provided the ability to differentiate those wood products with ASTM E 84 FSIs of 70 to 125 from those with higher FSIS. The burner settings of 100 and 160 kW are consistent with the likely upper limits for burner settings that will result in further significant reductions in the flashover times for untreated wood products. Lining the ceiling with the test materials provided a more severe test. The use of flashover criteria such as heat flux to floor and heat release rate should be used in conjunction with the visual observation of flames out the doorway.

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