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Comparison of Criteria for Room Flashover

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In structural fires flashover is characterized by the rapid transition in fire behavior from localized burning of fuel to the involvement of all combustibles in the enclosure. Major parameters affecting flashover are fire growth rate, ventilation opening area, and room area. A comparison of flashover criteria is undertaken using the Thomas, Babrauskas, and the CFAST/FASTLite criteria, concentrating on the similarities and differences between the criteria in their assessment of the major parameters affecting the time to reach flashover.

Introduction

IN structural fires flashover is characterized by the rapid transition in fire behavior from localized burning of fuel to the involvement of all combustibles in the enclosure. High-radiation heat-transfer levels from the original burning item, the flame and plume directly above it, and the hot smoke layer spreading across the ceiling are all considered to be responsible for the heating of the other items in the room, leading to their ignition. Factors affecting flashover include room size, ceiling and wall conductivity and flammability, and heat- and smoke-producing quality of room contents.

Kim and Lilley[1] used the FASTLite computer code [available from National Institute of Standards and Technology (NIST)] version 1.1.2, to compute developments in a typical single room up to flashover conditions. Although calculations have been made with the FASTLite computer code, equivalent results are given in the calculations with the CFAST computer code (also available from NIST). The FASTLite is a simpler variant of the CFAST computer code (see Ref. 2). With initial inside and outside room temperatures of 20°C (68°F) and humidity of 50%, it is expected that the time from ignition of the fire to reach flashover conditions depends upon many factors. It was found that the major parameters affecting flashover were fire growth rate, ventilation opening area, and room area.

The objective of the present contribution is to compare the flashover criteria of Thomas,[3] Walton and Thomas,[4] Babrauskas,[5] and the CFAST/FASTLite[6,7] computer code, concentrating on the similarities and differences between the criteria in their assessment of the major parameters affecting on the time to reach flashover.

Burning Rates

In general, the heat-release rate (heat energy evolving on a per unit time basis) of a fire $\dot{Q}$ (kilowatts) changes as the size of the fire changes, as a function of time t (seconds) after fire ignition. That is, the variation of $\dot{Q}$ vs t is extremely important in characterizing the rate of growth of a fire. Data are available for heat release rate vs time for many items [for example, see Babrauskas and Grayson[8] and Society Fire Protection Engineering Handbook[9] and the database in Bukowski et al.[10]]. Many of these experimental data are presented in a very useful standard parametric fashion in Kim and Lilley.[11]

In a more general methodology slow, medium, fast, and ultra-fast fire growths can be specified by the t^2-fire growth model, where, after an initial incubation period,

$$\dot{Q} = \alpha_f (t - t_0)^2$$

where α_f is a fire-growth coefficient (kW/s^2) and t_0 is the length of the incubation period (s). This t^2-fire was used in the authors' previous paper discussing parameter effects on the time to reach flashover conditions (see Ref. 1).

Flashover

Flashover is characterized by the rapid transition in fire behavior from localized burning of fuel to the involvement of all combustibles in the enclosure. High-radiation heat-transfer levels from the original burning item, the flame and plume directly above it, and the hot smoke layer spreading across the ceiling are all considered to be responsible for the heating of the other items in the room, leading to their ignition. Warning signs are heat buildup and rollover (small, sporadic flashes of flame that appear near ceiling level or at the top of open doorways or windows of smoke-filled rooms). Factors affecting flashover include room size, ceiling and wall conductivity and flammability, and heat- and smoke-producing quality of room contents. Water cooling and venting of heat and smoke are considered to be ways of delaying or preventing flashover. Often the determination of whether or not flashover is expected is the single most important fire computation because lethal conditions occur after flashover. This topic is addressed specifically in Drysdale[12] and Thomas et al.[13]

There is a need to assess which of the methods for predicting flashover is most appropriate. Babrauskas has compared the effect of room wall area on the energy release required for flashover, using the preceding methods. The results of his comparisons, along with some experimental data for rooms with gypsum board walls, show that the energy required for flashover depends intimately on both, normalized by the ventilation factor

$$A_0\sqrt{H_0}$$

It can be observed that over the range of compartment sizes of most interest all of the methods produce similar results. Flashover is characterized by the following:

1) Temperatures reach approximately 500°C (932°F) to 600°C (1112°F) in the upper portions of the room.

2) Heat flux of from 20 to 25 kW/m^2 (6340 to 7925 Btu/hrft^2) occurs at floor level, with near-simultaneous ignition of combustibles not previously ignited.

3) Filling of almost the entire room volume with smoke and flames occurs.

Method of Babrauskas

As the fire grows, Babrauskas[5] asserts that a simple method of predicting flashover is that the minimum fire heat-release rate in kilowatts for flashover to occur is

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$$\dot{Q}_{fo} = 750\, A_0\sqrt{H_0}$$

where A_0 is the window or door ventilation area in square meters and H_0 the height of opening in meters.

Method of Thomas

Recent evaluation (see Refs. 3 and 4) and comparison of improved estimates has led to the following expression for the minimum fire heat-release rate in kilowatts at flashover as

$$\dot{Q}_{fo} = 378\, A_0\sqrt{H_0} + 7.8A_w$$

where A_w is the wall area in square meters.

Method of FASTLite

The time to reach flashover is characterized in the FASTLite computer program single-room simulation by the upper-layer temperature reaching 600°C (1112°F).

Comparison of Flashover Criteria

Figure 1 shows the single room considered, with just one ventilation opening. Some geometric parameters are illustrated in the figure (numbers 1, 2, 3, 4, 5, 8, which are defined in the following list). There are 10 parameters of interest that affect the time required to reach flashover conditions, which is calculated in this paper. The parameters and their standard (default) values are as follows:

1) Floor area is 4 m × 4 m = 16 m^2.
2) Vent width is 2 m.
3) Vent height is 1 m (distance from bottom to top of the vent).
4) Vent height above floor is 1.5 m (distance from floor to midpoint of the vent).
5) Ceiling height is 2.4 m.
6) Fire specification equals medium fire.
7) Fire location equals fire in center of floor.
8) Wall and ceiling material is 0.016-m ($\frac{5}{8}$-in.)-thick gypsum board.
9) Fire radiation fraction is 0.3 (radiation heat loss fraction from the flame).
10) Fire maximum heat-release rate is 3 MW.

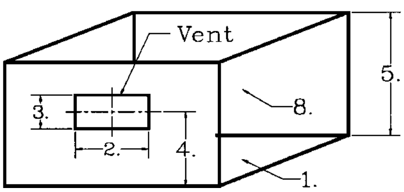

Fig. 1 Parameters investigated.

Calculations to be exhibited are made with these parameters held at their standard (default) values, except the one parameter that is varied in order to show its effect in the figures and tables. That is, calculations to be exhibited all have vent height = 2 m, ceiling height = 2.4 m, fire location in center of flow, wall and ceiling material to be 0.016-m ($\frac{5}{8}$-in.)-thick gypsum, fire radiation fraction = 0.3, and fire maximum heat-release rate = 3 MW.

During fire growth, conduction heat loss is most pronounced through the ceiling and walls, with little heat loss through the floor. In the Thomas flashover criterion the total enclosure surface area is used, but the contribution of floor area to the total surface area is sometimes omitted. Our calculations will clarify this effect. In the case of the Thomas criterion, including the floor area in the total enclosure, surface area is indicated by "Thomas 1," while excluding it is indicated by "Thomas 2."

Previous studies[1] have shown that the major parameters affecting flashover are fire growth rate, ventilation opening area, and room area. Hence, the focus of the calculations and how the various criteria differ will be on precisely these important parameters.

Figure 2 shows the calculations of the time to reach flashover conditions vs fire growth specification and ventilation factor, for a room of floor area 3 × 4 m^2. Figures 3 and 4 show similar calculations with room areas 6 × 8 m^2 and 12 × 16 m^2, respectively. The effect of greater room size is to increase the time required to reach flashover, in the case of Thomas and CFAST/FASTLite criteria. It has no effect with the Babrauskas criterion because enclosure surface area does not play a part in the Babrauskas criterion. As room size increases, the CFAST/FASTLite criterion gives very large flashover times, which are at odds with the other criteria considered.

These data are conveniently given in Table 1 with two additional room sizes also included, where fire growth specification, room size,

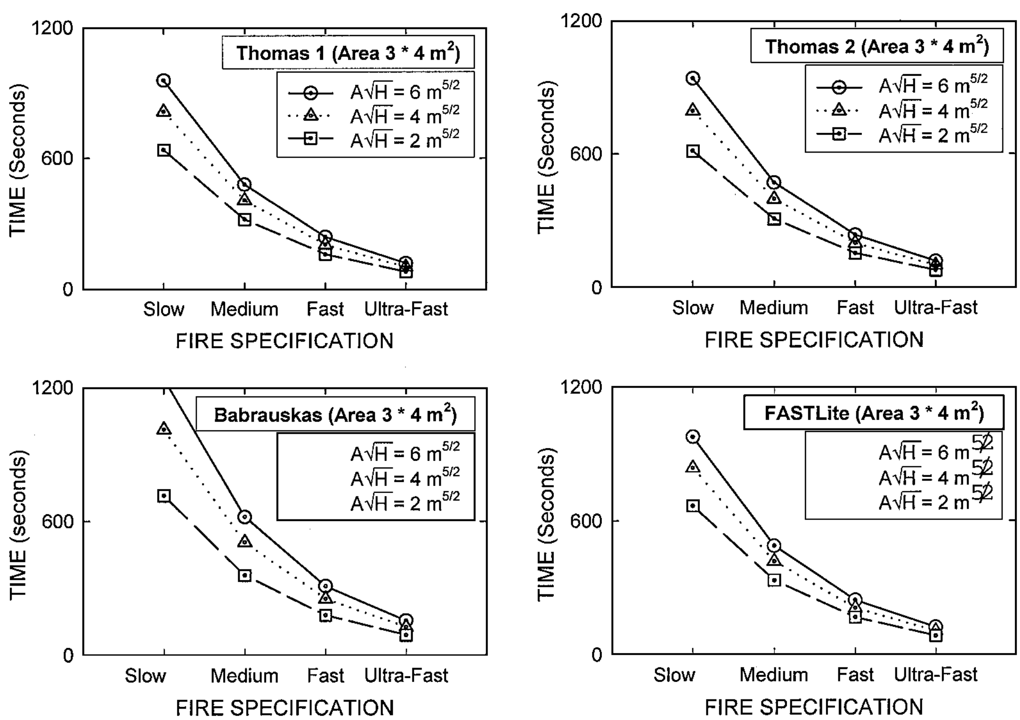

Fig. 2 Time to reach flashover conditions vs fire growth specification and ventilation factor, for a room of area 3 × 4 m^2.

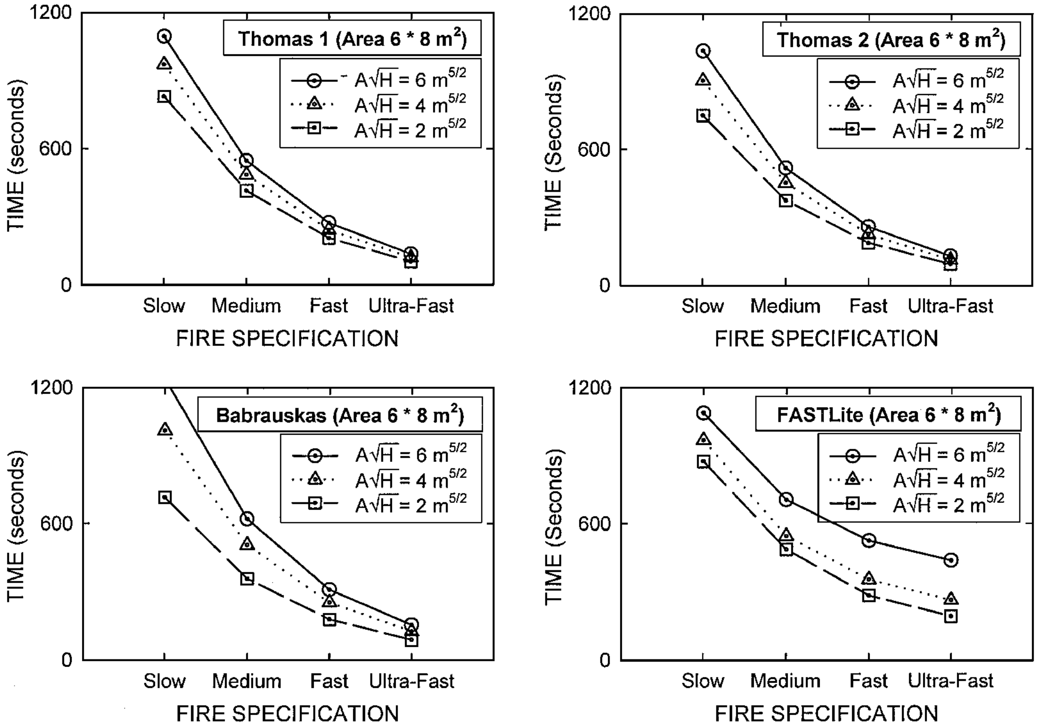

Fig. 3 Time to reach flashover conditions vs fire growth specification and ventilation factor, for a room of area 6 × 8 m^2.

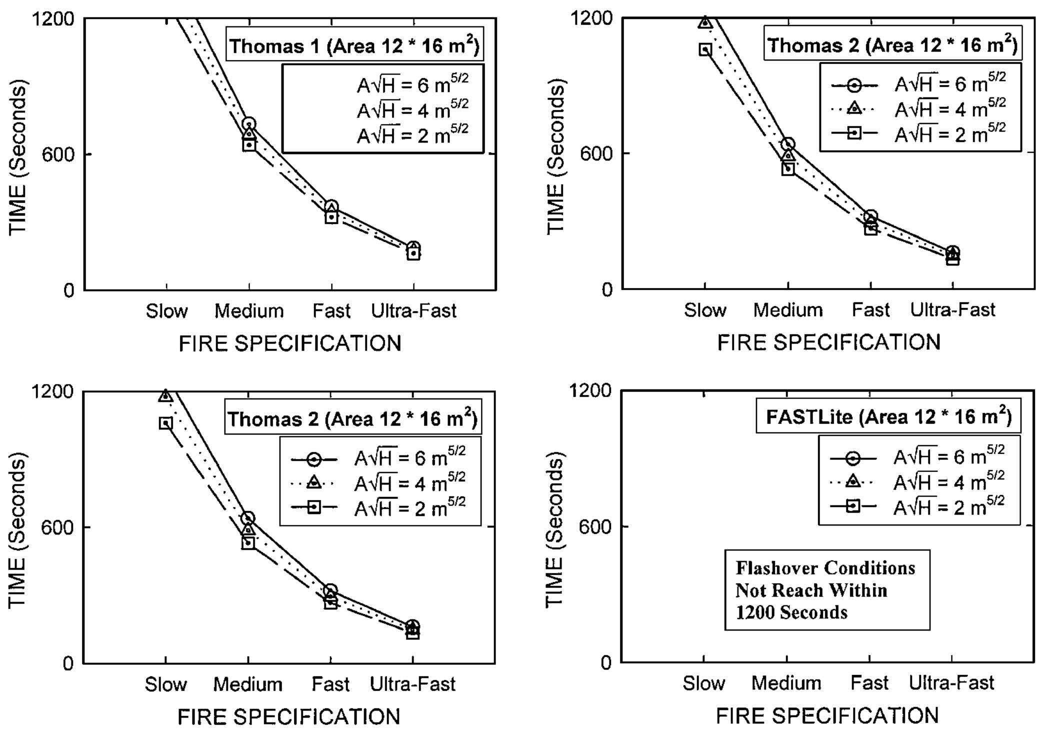

Fig. 4 Time to reach flashover conditions vs fire growth specification and ventilation factor, for a room of area 12 × 16 m^2.

ventilation factor, and flashover criterion being used are all considered. These four parameters affect strongly the calculated time from inception of the fire to reach flashover conditions. Notice the very large flashover times calculated via the CFAST/FASTLite criteria in the case of the largest room area considered. Also notice that X in some locations in the table indicates that flashover conditions were never reached in the CFAST/FASTLite computer calculations, for the particular values of largest room size and the two largest ventilation factors considered.

Table 2 gives an indication of the variance between the four flashover criteria for each of the situations considered in Table 1. One can thus judge the extent to which the criteria differ in their calculations of time to reach flashover conditions. Each line of maximum, minimum, average, and normalized range (=(max − min)/average) is obtained via observation of the four times to flashover given by the four criteria (Thomas 1, Thomas 2, Babrauskas, and FASTLite) for the one situation of interest. When flashover was not predicted by one of the four criteria, the calculation was made on the basis of

Table 1 Calculated time (seconds) to reach flashover according to ventilation factor, rapidity of fire growth, room area and four different criteria

		6 $m^{5/2}$ (2 m high × 2.12 m wide)				4 $m^{5/2}$ (2 m high × 1.41 m wide)				2 $m^{5/2}$ (2 m high × 0.71 m wide)			
Vent factor		T1	T2	B	FL	T1	T2	B	FL	T1	T2	B	FL
Slow	3*4*2.4	957.1	940.3	1239.3	933.5	813.5	793.7	1011.9	785.6	638.4	612.9	715.5	602.4
	4*6*2.4	1009.1	977.0	1239.3	949.7	874.1	836.8	1011.9	857.7	714.0	667.8	715.5	747.1
	6*8*2.4	1094.2	1034.1	1239.3	1088.3	971.1	902.9	1011.9	968.9	829.9	749.0	715.5	874.4
	8*12*2.4	1236.7	1128.7	1239.3	2041.1	1129.3	1009.8	1011.9	1282.7	1010.4	874.9	715.5	1076.6
	12*16*2.4	1463.8	1277.4	1239.3	X	1374.2	1173.6	1011.9	X	1278.4	1059.8	715.5	2039.9
Medium	3*4*2.4	478.6	470.1	619.6	466.7	406.8	396.8	505.9	392.8	319.2	306.5	357.8	301.2
	4*6*2.4	504.6	488.5	619.6	506.0	437.1	418.4	505.9	461.9	357.0	333.9	357.8	410.7
	6*8*2.4	547.1	517.1	619.6	705.0	485.5	451.4	505.9	545.1	414.9	374.5	357.8	486.2
	8*12*2.4	618.4	564.3	619.6	1677.4	564.6	504.9	505.9	915.5	505.2	437.4	357.8	715.9
	12*16*2.4	731.9	638.7	619.6	X	687.1	586.8	505.9	X	639.2	529.9	357.8	1689.0
Fast	3*4*2.4	239.2	235.0	239.2	233.3	203.3	198.4	252.9	196.4	159.6	153.2	178.8	150.6
	4*6*2.4	252.2	244.2	239.2	300.3	218.5	209.2	252.9	250.0	178.5	166.9	178.8	225.5
	6*8*2.4	273.5	258.5	239.2	524.2	242.7	225.7	252.9	354.2	207.4	187.2	178.8	283.6
	8*12*2.4	309.1	282.1	239.2	1500.0	282.3	252.4	252.9	738.5	252.6	218.7	178.8	542.1
	12*16*2.4	365.9	319.3	239.2	X	343.5	293.3	252.9	X	319.5	264.9	178.8	1517.7
Ultra-fast	3*4*2.4	119.6	117.5	119.6	116.7	101.7	99.2	126.5	98.2	79.8	76.6	89.4	75.3
	4*6*2.4	126.1	122.1	119.6	207.6	109.2	104.6	126.5	145.4	89.2	83.5	89.4	123.3
	6*8*2.4	136.7	129.2	119.6	437.4	121.4	112.8	126.5	263.5	103.7	93.6	89.4	193.1
	8*12*2.4	154.6	141.1	119.6	1417.6	141.1	126.2	126.5	652.9	126.3	109.3	89.4	457.1
	12*16*2.4	183.9	159.6	119.6	X	171.7	146.7	126.5	X	159.8	132.4	89.4	1432.4

T1 = Thomas 1 criterion including floor area in total surface area.
T2 = Thomas 2 criterion excluding floor area in total surface area.
B = Babrauskas criterion.
FL = FASTLite computer calculations to reach 600°C.

Table 2 Indication of the variance between the four flashover criteria for each of the situations considered in Table 1

		6 $m^{5/2}$ (2 m high × 2.12 m wide)				4 $m^{5/2}$ (2 m high × 1.41 m wide)				2 $m^{5/2}$ (2 m high × 0.71 m wide)			
Vent factor		Max.	Min.	NR	Ave.	Max.	Min.	NR	Ave.	Max.	Min.	NR	Ave.
Slow	3*4*2.4	1239.3	933.5	0.30	1017.6	1011.9	785.6	0.27	851.2	715.5	602.4	0.18	642.3
	4*6*2.4	1239.3	949.7	0.28	1043.8	1011.9	836.8	0.20	895.1	747.1	667.8	0.11	711.1
	6*8*2.4	1239.3	1034.1	0.18	1114.0	1011.9	902.9	0.11	963.7	874.4	715.5	0.20	792.2
	8*12*2.4	2041.1	1128.7	0.65	1411.4	1282.7	1009.8	0.25	1108.4	1076.6	715.5	0.39	919.3
	12*16*2.4	1463.8	1239.3	0.17	1326.8	1374.2	1011.9	0.31	1186.6	2039.9	715.5	1.04	1273.4
Medium	3*4*2.4	619.6	466.7	0.30	508.7	505.9	392.8	0.27	425.6	357.8	301.2	0.18	321.2
	4*6*2.4	619.6	488.5	0.25	529.7	505.9	418.4	0.19	455.8	410.7	333.9	0.21	364.9
	6*8*2.4	705.0	517.1	0.31	597.2	545.1	451.4	0.19	497.0	486.2	357.8	0.31	408.4
	8*12*2.4	1677.4	564.3	1.28	869.9	915.5	504.9	0.66	622.7	715.9	357.8	0.71	504.1
	12*16*2.4	731.9	619.6	0.17	663.4	687.1	505.9	0.31	593.3	1689.0	357.8	1.66	804.0
Fast	3*4*2.4	239.2	233.3	0.03	236.7	252.9	196.4	0.27	212.8	178.8	150.6	0.18	160.5
	4*6*2.4	300.3	239.2	0.24	259.0	252.9	209.2	0.19	232.6	225.5	166.9	0.31	187.4
	6*8*2.4	524.2	239.2	0.88	323.9	354.2	225.7	0.48	268.9	283.6	178.8	0.49	214.3
	8*12*2.4	1500.0	239.2	2.16	582.6	738.5	252.4	1.27	381.5	542.1	178.8	1.22	298.0
	12*16*2.4	365.9	239.2	0.41	308.1	343.5	252.9	0.31	296.6	1517.7	178.8	2.35	570.2
Ultra-fast	3*4*2.4	119.6	116.7	0.02	118.4	126.5	98.2	0.27	106.4	89.4	75.3	0.18	80.3
	4*6*2.4	207.6	119.6	0.61	143.9	145.4	104.6	0.34	121.4	123.3	83.5	0.41	96.3
	6*8*2.4	437.4	119.6	1.54	205.7	263.5	112.8	0.97	156.1	193.1	89.4	0.86	120.0
	8*12*2.4	1417.6	119.6	2.83	458.2	652.9	126.2	2.01	261.7	457.1	89.4	1.88	195.5
	12*16*2.4	183.9	119.6	0.42	154.4	171.7	126.5	0.30	148.3	1432.4	89.4	2.96	453.5

*NR = normalized range = (max − min)/average.

the other three alone. Slow fire growth with large rooms appears in general to have large discrepancies between the alternate criteria, as observable via the "normalized range" values, and cases where flashover was not predicted by one of the criteria.

Conclusions

Flashover is characterized by the rapid transition in fire behavior from localized burning to the involvement of all combustibles in the enclosure. Major parameters affecting flashover are fire growth rate, ventilation opening area, and room area. A comparison of flashover criteria was undertaken using the Thomas, Babrauskas, and the CFAST/FASTLite criteria, concentrating on the similarities and differences between the criteria in their assessment of the major parameters affecting flashover.

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