REVIEW ON TWO PERFORMANCE-BASED TESTS FOR ASSESSING FLAME SPREAD IN HONG KONG

C.W. Leung
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong

(Received 2 April 2003; Accepted 20 May 2003)

ABSTRACT

Awareness has been raised in developing a new assessing strategy on flame spread over construction and lining materials in Hong Kong. The ISO 9705 full-scale burning test is well recognized as an ideal tool for collecting scientific results comparable to real fire data. Due to its high cost, new tests have been developed and existing tests are under modification as alternative assessing tools. In this paper, two tests, i.e. the Single Burning Item test and the Reduced-scale Model Box test are reviewed. They are reasonable alternatives to the ISO 9705 and can be considered in the development of a new performance-based fire test for flame spread in Hong Kong.

1. INTRODUCTION

Flame spread is one of the essential factors affecting the heat release rate and thus the fire size in a room. To carry out the fire hazard assessment in a compartment, flame spread over materials should be studied very carefully. The local specifications on flame spread over materials were reviewed [1,2]. The bench-scale test, BS476: Part 7 [3] is the only test specified in the local fire codes [4-7]. This test is considered inadequate to reflect the actual behaviours of materials, especially sandwich panels and composite materials in actual fires. In the development of performance-based fire codes, it is essential to have an appropriate tool to assess the flame spreading properties of materials. The ISO 9705 full-scale burning test [8] is well recognized for providing useful results comparable to real fire data. Materials can be tested in a compartment representing a general room size in their end-use conditions. This test was recommended [1,2] to the local government. However, there are some drawbacks on specifying this test as the regulatory assessing tool. The test is expensive and comparatively time-consuming to be carried out. Large amount of materials are involved and this might not be economical for product development and testing for quality control. Large production of smoke might induce environmental problems. Smoke filtration plant can be installed to reduce the hazard but there are uncertainties on the long-term health effects on citizens. It is hard to find a suitable place in Hong Kong for building such a facility. Using the PolyU/HEU Assembly Calorimeter developed by The Hong Kong Polytechnic University (PolyU) and the Harbin Engineering University (HEU) [9] in Harbin for testing of materials is a good choice. However, it takes time to transport materials to the site and it might not be suitable under the tight project schedules. Having similar concerns, intermediate performance-based tests like the Single Burning Item (SBI) test [10] developed in Europe and the Reduced-scale Model Box (RMB) test [11] developed in Japan were developed to give scientific results and validated with the ISO 9705. In this paper, those two tests are reviewed. They are worthwhile to be considered in the development of new fire codes.

2. THE SINGLE BURNING ITEM TEST

In the Member States of the European Commission, national standards will be transited to a new harmonized system. Products to be sold across Europe will be progressively included in this system. The SBI was established as one of the harmonized test methods on evaluating fire behaviour of all construction products, excluding floor coverings under the Euroclass system [12]. This test was evolved from the requirements of European fire regulators for a standard test to simulate a single item such as a wastebasket burning close to the corner of a room and growing to flashover. It was approved as an European Standard, EN 13823 by CEN in 2001 and established as an British Standard BS EN 13823 in 2002.

The SBI is an intermediate scale test. Specimens are to be mounted according to their end-use conditions on two vertical specimen holders forming a right-angled corner configuration as shown in Fig. 1. The standard specimen size to be tested is 2.25 m^2 with maximum thickness of 200 mm.

3. THE REDUCED-SCALE MODEL BOX TEST

The RMB was established in Japan in early 1980's as a one-third scaled model of the ISO 9705 to reduce the total cost and for studying the postflashover conditions. Materials are lined on the three walls and ceiling of a chamber 1.68 m (L) by 0.84 m (W) by 0.84 m (H) with a doorway of 0.3 m by 0.67 m (H) as shown in Fig. 2. The test was accepted as a Japanese standard, JP Notification No. 1321 [11] in 1984 and it is being revised as an international standard under the ISO technical programme ISO TC 92/SC1 [13].

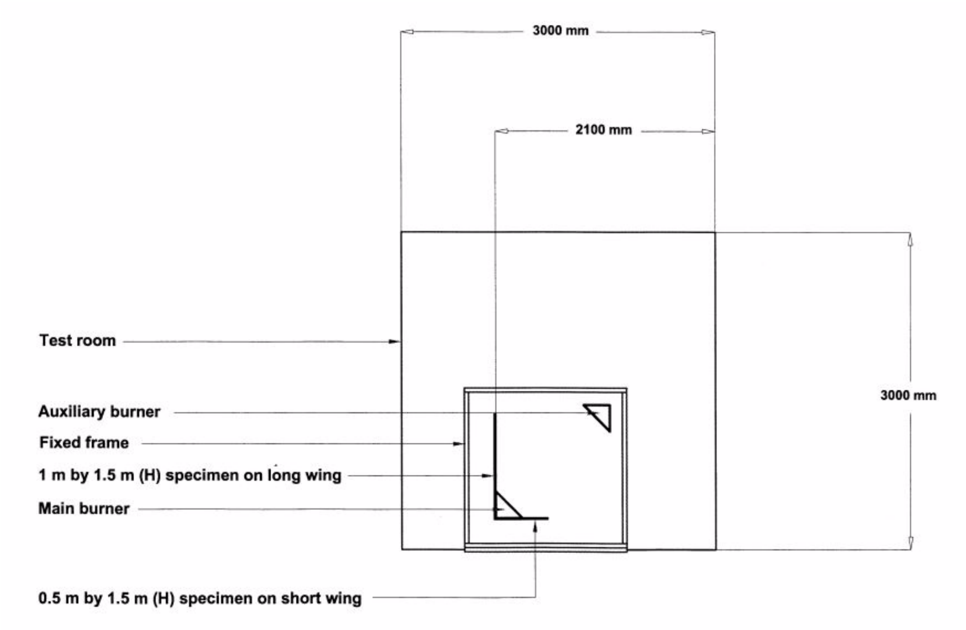

Fig. 1: Layout plan of the SBI

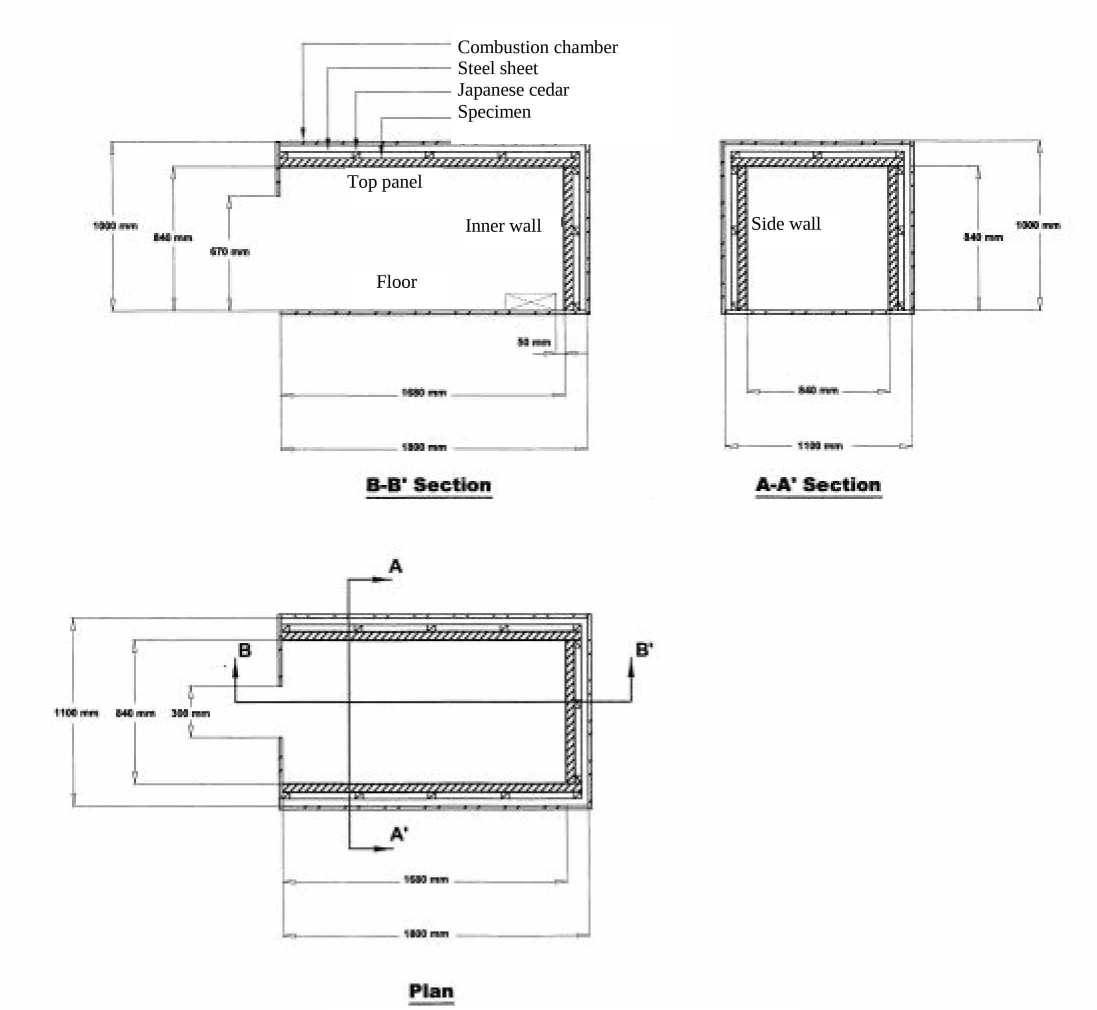

Fig. 2: Configuration of the RMB [11]

4. HEAT SOURCE

- SBI

Two identical right-angled triangular propane-fuelled burners with side length of 250 mm are used in the SBI. The main burner is located at the bottom of the specimen position to give a heat output of 30 kW and maximum heat exposure of about 40 kWm^{-2}. An auxiliary burner is fixed on a frame opposite to the specimen corner with the top at 1450 mm above the floor as shown in Fig. 3. It is ignited at 120 s, before the beginning of the test for the measurement of the heat output from the burner. At 300 s, the propane gas supply should be diverted to the main burner. The test can be started with the ignition of the burner.

- RMB

In the JP Notification [11], the fire source in the RMB is a wood crib 0.09 m^2 by 10 mm (H) with insulation boards soaked with denatured methyl alcohol. In recent review studies of the RMB [e.g. 14], a square porous propane burner was used to give a more steady and continuous heat output. Two sizes of 0.17 m^2 and 0.3 m^2 were used, both with a heat output of 40 kW. This value was taken as slightly less than half of the critical intensity, estimated to be 85 to 100 kW, such that direct cause to flashover can be prevented. Further, this value was considered as almost the minimum to reproduce the burner output of 100 kW to 300 kW as in the ISO 9705.

The flame height from the SBI burner was criticized to be too high, with the flame tip extended over the top of the specimen. Ignition and upward flame spread from the flame source cannot be observed [15].

An estimation of the flame height in the wall corner geometry was made [16],

$$H/D = 3 \cdot Q^{*2/3} \tag{1}$$

$$Q_{total} = 1100\ (kWm^{-1}) \cdot D^{5/2} \cdot Q^* \tag{2}$$

where H (in m) is the continuous flame height, where flame exists 100 percent of the time; D (in m) is the diameter of the burner; Q_{total} (in kW) is the total heat release required to produce the flame height, H; 1110 kWm^{-1} is the heat release rate per unit area for heptane pool fire and Q* is the effective heat of combustion.

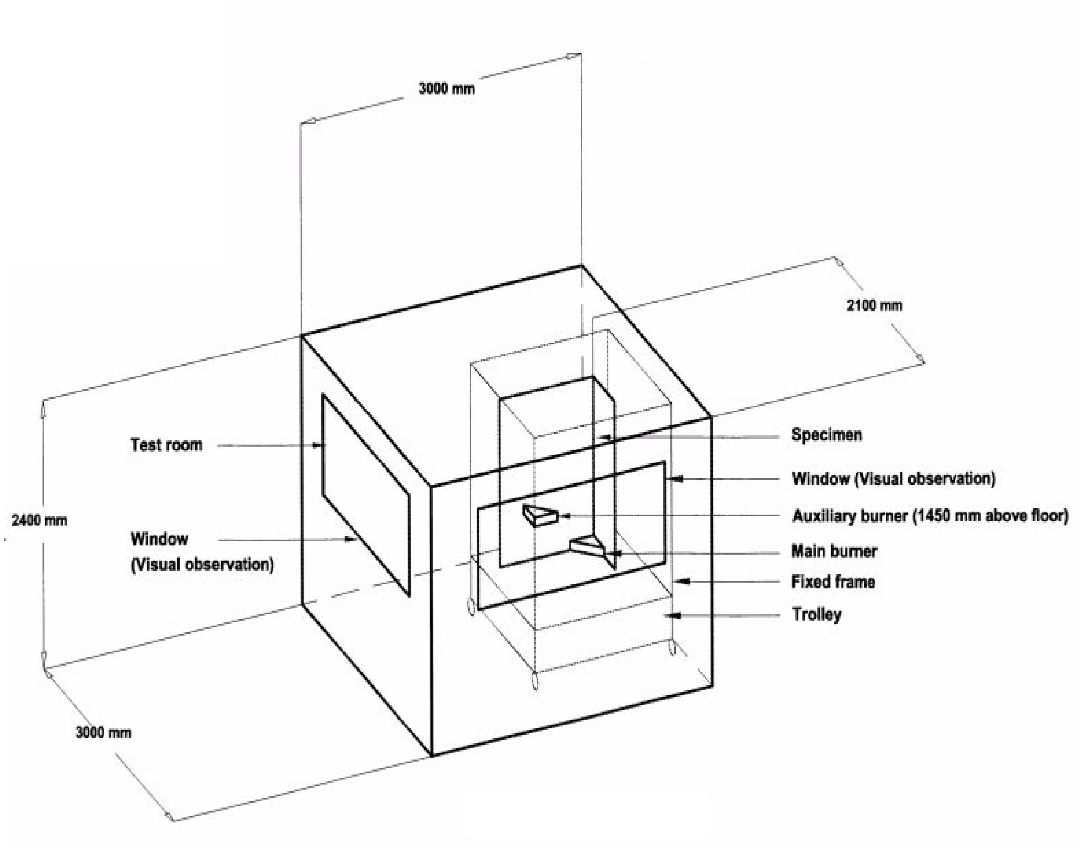

Fig. 3: Configuration of the SBI

The equivalent side length of the triangular SBI burner was taken as 0.15 m. H was taken as the maximum height of the specimen, 1.5 m. Q_{total} was determined to be 59 kW. This result, on the other hand, justifies that the burner alone with 30 kW would not cause a flame height higher than the specimen. A similar estimation is carried out for the proposed RMB burner. The fraction, H/D in the RMB is much smaller, with Q* as 2.1 and Q_{total} as 28 kW for the 0.17 m^2 burner and 49 kW for the 0.3 m^2 burner. As the burner output was selected to be 40 kW, this is much higher than the Q_{total} determined for the 0.17 m^2 burner. The flame height would be far too high and this would cause direct thermal attack to the ceiling. The upward flame spread would be mainly caused by the burner but not based on the flame spreading properties of the material itself. It might also accelerate the flame spread around the corner and advance the lateral flame spread to the other part of the specimen.

5. TESTING ENVIRONMENT

- SBI

Specimens are attached vertically on two panels including a long wing of 1.0 m by 1.5 m (H) and a short wing of 0.5 m by 1.5 m (H) forming a corner configuration. The whole setup is installed on a trolley to be placed in a fixed frame inside a test room of 3.0 m (L) × 3.0 m (W) by 2.4 m (H). A clearance of 2.1 m between the long wing and the wall should be maintained as shown in Fig. 1. Glasses are placed in the two walls facing the front side of the two specimen planes for observation of the testing process. The only air inlet is an opening with perforated plates on the floor. The opening area is 40 % to 60 % of the total area of 1.38 m by 0.4 m with perforation diameter of 8 mm to 12 mm. This allows an evenly distributed flow along the floor of the test room. Specimens are tested under fully ventilated condition throughout the test under sufficient oxygen supply. An exhaust hood is located above the trolley. It is connected to the exhaust fan maintained at an extraction rate of 0.6 m^3s^{-1} such that no ceiling layer and hot gas layer would be formed. Heating of the unburned surfaces mainly depends on the radiation from the flame and convective heat transfer.

The duration of test is 20 minutes unless

- the heat release rate of the specimen of 350 kW or a mean value of 280 kW over a period of 30 s is exceeded,
- the exhaust duct temperature of 400 ^oC or a mean value of 300 ^oC over a period of 30 s is exceeded, or
- the flame of the burner is disturbed by falling materials,

such that the test can be terminated early.

According to the testing results for various materials [17], vertical flame spread was observed to be dominated. This is caused by the thermal attack from the main burner and the upward wind flow induced by natural air entrainment. Only limited or slow lateral flame spread was observed. Flame spread more quickly in the corner.

- RMB

Similar to the ISO 9705 full-scale burning test, materials are tested inside a small compartment with an opening. Specimens are attached on the ceiling and the three walls of the model box excluding the wall with the doorway subject to their on-site installation conditions. A hot gas layer would be formed at high level inside the room. This would cause radiative feedback to preheat and/or ignite the parts of the specimen where flame spread is not yet reached. The test should be continued for 15 minutes or until all the specimens inside the model box are consumed.

Materials at the rear corner around the burner would be ignited first. The fire would change from a full-ventilated fire in the growth stage to a ventilation-controlled fire as flashover is approached. The doorway in the ISO 9705 is 0.8 m by 2.0 m (H) (1.6 m^2) with a ventilation factor, $AH^{0.5}{}_{ISO}$ of 2.26 $m^{2.5}$. In the RMB, the door size is 0.3 m by 0.67 m (H) (0.201 m^2) with $AH^{0.5}{}_{RMB}$ of 0.165 $m^{2.5}$ which is 7 % of $AH^{0.5}{}_{ISO}$. The minimum heat release rate to flashover, Q_{minf} (kW) in a room $L \times W \times H$ (m^3) with an opening of area A_v (m^2) and height H_v (m) can be estimated by using the equation proposed by Thomas [18]:

$$Q_{minf} = 7.8\, A_T + 378\, A_v H_v^{0.5} \quad (3)$$

where A_t is the total area of compartment surface (m^2) given by

$$A_T = 2\,[L \times W + (L + W) \times H] - A_v \quad (4)$$

The total areas of materials to be tested in the RMB and ISO 9705 are 6.9 m^2 and 44.5 m^2. Comparing the minimum heat release rate to flashover for the same materials in the two tests, Q_{minf} is 116 kW in the RMB which is 10 % of the value in the ISO 9705 (1200 kW).

Since the heat release rate at flashover is estimated to be over 1 MW in the ISO 9705, the test was designed to be terminated after flashover due to safety reasons. While in the RMB, the test can be continued for further collection of useful data at flashover and postflashover stage.

6. TEST RESULTS/CLASSIFICATION

The data to be collected in both tests are similar to the ISO 9705. Those include the exhaust volume flow rate, heat release rate, concentrations of oxygen, carbon monoxide, carbon dioxide and smoke production rate.

- SBI

According to the European Commission Decision, construction products excluding floorings should be tested according to the harmonized product standards [10, 19-21] and to be classified into seven classes, Class A1, A2, B to F. The SBI is applicable for Classes A2, B, C and D in which most of the practical wall and ceiling lining materials are intended to fall into. Classes A2 and B are materials with practically no flame spread, very limited smoke production and no flaming droplets or particles. Class C are materials with very limited flame spread, flaming droplets, limited ignitability, heat release and smoke. Class D materials would have limited flame spread, smoke, flaming droplets, acceptable ignitability and heat release [17].

Materials are classified based on the FIre Growth RAte (FIGRA) index (Ws^{-1}), the SMOke Growth RAte (SMOGRA) index (m^2s^{-2}), the total heat release, THR_{600s} and the extent of lateral flame spread over the long wing.

The FIGRA and SMOGRA indices are determined from the maximum of the functions of the average of HRR(t) (kW), $HRR_{av}(t)$, the average of SPR(t) (m^2s^{-1}), $SPR_{av}(t)$ and the time of the occurrence, t by

$$FIGRA = 1000 \times \max.\left(\frac{HRR_{av}(t)}{t-300}\right) \quad (5)$$

$$SMOGRA = 10000 \times \max.\left(\frac{SPR_{av}(t)}{t-300}\right) \quad (6)$$

$HRR_{av}(t)$ is the average of HRR(t) over 30 s for t ≥315 s,

$$HRR_{30s}(t) = \frac{0.5HRR(t-15) + HRR(t-12)}{10} + \ldots$$
$$\ldots + \frac{HRR(t+12) + 0.5HRR(t+15)}{10} \quad (7)$$

$SPR_{av}(t)$ is the average of SPR(t) over 60 s for t ≥330 s,

$$SMOGRA_{60s}(t) = \frac{0.5SPR(t-30) + HRR(t-27)}{20} + \ldots$$
$$\ldots + \frac{HRR(t+27) + 0.5HRR(t+30)}{20} \quad (8)$$

$HRR_{av}(t)$ for t < 315 s and $SPR_{av}(t)$ for t < 330s, the average should be taken over the widest possible symmetrical range of data points within the exposure period. This allows the presentation of the heat release rates and smoke production rates in a continuous scale. FIGRA(ISO 9705) and SMOGRA(ISO 9705) indices have been calculated [22] for the ISO 9705. The definitions of the two indices are different from the those in the SBI.

FIGRA(ISO 9705) (in kWs^{-1}) was defined as the peak heat release rate of the fire, excluding the contribution of the fire source, divided by the time at which such value is reached.

SMOGRA(ISO 9705) (in m^2s^{-2}) was defined as the 60 s average of peak smoke production divided by the time at which the value is reached and multiplied with a factor 1000 to achieve practical values for similar magnitude as the FIGRA(ISO 9705) index.

Calculating the indices using the peak values of heat release rate and smoke production rate would cause problems for materials with a small peak shortly after the beginning of the test and then a higher peak value at the end of the test, especially when the heat output is increased in the ISO 9705. Using the higher peak value and corresponding longer time might have a smaller index. This might not be sensitive enough to reflect the hazard of having a comparatively high heat release in a short time under low burner output. This problem is solved by taking the maximum value as in Equations 5 and 6 used in the SBI. On the other hand, the FIGRA threshold values may lead to irrelevant fire scenarios for products with transient flame spread having small flashes or short heat release peak at the beginning [23].

In the SBI, additional classification should be made on smoke production (Classes s1, s2 and s3) and flaming droplets (d0, d1 and d2). The classification criteria are shown in Table 1. The time to ignition can be observed visually and to be measured when the increase in heat release rate exceeds 5 kW or the temperature rise exceeds 3 K [17].

The test scheme and classification system of the SBI have been criticized [15]. The data was commented as much less informative than the cone calorimeter test [24].

Table 1: Classes of reaction to fire performance for construction products excluding floorings [12]

<table>
<tr><th>Class</th><th>Test</th><th>Classification criteria in SBI</th><th>Additional classification in SBI</th></tr>
<tr><td>A1</td><td>EN ISO 1182;
EN ISO 1716</td><td>-</td><td>-</td></tr>
<tr><td>A2</td><td>EN ISO 13823, SBI
EN ISO 1182;
EN ISO 1716</td><td>FIGRA ≤ 120 Ws^{-1}
LFS < edge of specimen
THR_{600s} ≤ 7.5 MJ</td><td rowspan="4">• Smoke production
• s1: SMOGRA ≤ 30m^2s^{-2};
TSP600s ≤ 50m^2
• s2: SMOGRA ≤ 180 m^2s^{-2};
TSP600s ≤ 200m^2
• s3: not s1 or s2

<u>Flaming droplets/ particles</u>
• d0: No flaming droplets/particles within 600s
• d1: No flaming droplets/particles persisting longer than 10s within 600s
• d2: not d0 or d1</td></tr>
<tr><td>B</td><td>EN ISO 13823, SBI
EN ISO 11925-2,
30 s exposure</td><td>FIGRA ≤ 120 Ws^{-1}
LFS < edge of specimen
THR_{600s} ≤ 7.5 MJ</td></tr>
<tr><td>C</td><td>EN ISO 13823, SBI
EN ISO 11925-2,
30 s exposure</td><td>FIGRA ≤ 250 Ws^{-1}
LFS < edge of specimen
THR_{600s} ≤ 15 MJ</td></tr>
<tr><td>D</td><td>EN ISO 13823, SBI
EN ISO 11925-2,
15 s exposure</td><td>FIGRA ≤ 750 Ws^{-1}</td></tr>
<tr><td>E</td><td>EN ISO 11925-2,
15 s exposure</td><td>-</td><td>-</td></tr>
<tr><td>F</td><td>No performance</td><td>-</td><td>-</td></tr>
</table>

Note:
FIGRA Fire Growth Rate
LFS Lateral Flame Spread on the long wing
SMOGRA Smoke Growth Rate
TSP_{600s} Total Smoke Production from the specimen in the first 600 s of exposure to the main burner flames (300 s to 900 s)
THR_{600s} Total Heat Release from the specimen in the first 600 s of exposure to the main burner flames (300 s to 900 s)

- RMB

Surface lining materials used in buildings in Japan should be assessed under five testing schemes [11] before 2000 [25]. Materials are classified into three classes, Class I, II and III representing non-combustibles, quasi-non-combustibles and fire retardants. Class II materials should be tested in the RMB. This class represents most of the surface lining materials commonly used in Japan. The passing criteria are based on the heat release rate data only. The peak heat release rate should be less than 170 kJs^{-1} and the total heat release should not exceed 5 MJ within the total testing period of 15 minutes. The classification system is shown in Table 2. Such performance criteria are under further development.

7. DISCUSSION ON RESULTS

To the best of knowledge, there is not yet data on comparing the results from the SBI and the RMB open to the general publics. Attempts were made to compare the two tests with ISO 9705 using data available in the literature [14,17,22,26].

- SBI

In the SBI round robin tests [17], 28 materials including wood products, mineral wool, paint, cellular plastics, wallcoverings, wallboards and plastics were selected. Three tests were carried out on each material in 15 laboratories. Details of the materials are shown in Table 3. Euroclasses of the particular materials were given based on the FIGRA indices and THR_{600s}. Mean values of the results are shown in Table 4. The results are compared with the ISO data, time to flashover and time to peak heat release rate in the ISO 9705 [22].

Table 2: Classes of reaction to fire performance for surface lining materials used in buildings in Japan [11]

Class	Test method	Classification criteria
Class I	Non-combustibility test	$\Delta T \leq 50\ ^oC$ $td\theta < 0\ ^oC$ minutes $C_A < 30$
	Surface test	$td\theta < 0\ ^oC$ minutes $C_A < 30$ duration of flames < 30 seconds
Class II	Surface test	$td\theta < 100\ ^oC$ minutes $C_A < 60$ duration of flames < 60 seconds
	Hole test	$td\theta < 150\ ^oC$ minutes $C_A < 60$
	RMB test (JP Notification No. 1231)	THR < 5 MJ HRRmax < 170 kJ
	Gas toxicity test	Time to the mice stop moving (the test specimen must have a time that is equal to or less than the time for the reference material)
Class III	Surface test	$td\theta < 350\ ^oC$ minutes $C_A < 120$
	Gas toxicity test	Time until the mice stop moving (the test specimen must have a time that is equal to or less than the time for the reference material)

- Euroclass B

  Twelve materials were classified as Euroclass B. Two materials reached flashover shortly after the burner output was stepped up to 300 kW. No flashover occurred in the other specimens and the peak heat release rate with values less than 150 kW was reached after the increase in the burner heat output. Three materials had the peak heat release rate at the end of the test.

- Euroclass C

  Three Euroclass C materials showed distinct results in the ISO 9705. No flashover was recorded for two materials. One reached the peak heat release rate shortly after the increase in burner output and one reached the peak at the end of the test. One material reached flashover shortly in the beginning of the test, giving out a heat release rate of more than 1 MW. The FIGRA requirement in the Euroclassification system was also exceeded for this material. More testing results are required for further validation.

- Euroclass D

  Materials classified as Euroclass D include 7 wood products and 1 gypsum with PVC wall carpet. All wood products reached flashover at around 3 minutes after the starting of the test, when the burner output was still 100 kW. The PVC covered gypsum showed an outstanding result. Flashover occurred when the burner was stepped up to 300 kW. Over 1 MW of heat was released in all cases.

- Euroclass E

  Although Euroclass E materials are not necessarily to be tested in the SBI, a comparison with the ISO 9705 results showed that flashover occurred shortly, less than 1.5 minute in the beginning of the test for those materials and the maximum heat release rate was over 1 MW.

Table 3: Product descriptions of the materials tested in the SBI round robin tests [17,26]

Code	Product name	Thickness/ mm	Nominal density/ kgm^{-3}
M01	Paper-faced gypsum plasterboard	13	700
M02	FR PVC	3	1180
M03	FR extruded polystyrene board	40	32
M04	PUR foam panel with aluminium foil faces	40	PUR: 40
M05	Spruce laths (joinery timber), vanished	10	380
M06	FR chip board	12	780
M07	FR Polycarbonate panel, 3-layered	16	175
M08	Painted paper-faced gypsum plasterboard	13	700
M09	Paper wall covering on gypsum plasterboard	13	700
M10	PVC wall carpet on gypsum plasterboard	13	700
M11	Plastic-faced steel sheet on mineral wool	0.15+1+50	Wool: 160
M12	Spruce laths (joinery timber), unvarnished	10	450
M13	Gypsum plasterboard on polystyrene	13+100	700; 20
M14	Phenolic foam	40	
M15	Intumescent coat on particle board	12	700
M16	Melamine faced medium density fibre (MDF) board	12	MDF: 750
M17	PVC water pipe	diam.:32; d:2	
M18	PVC covered electric cables		
M19	Unfaced rockwool	50	145
M20	Melamine faced particle board	12	
M21	Steel sheet on expanded polystyrene sandwich panel	0.5+100	EPS: 20
M22	Ordinary particle board	12	700
M23	Ordinary plywood (birch)	12	650
M24	Paper wall covering on particle board	12	700
M25	Medium density fibreboard	12	700
M26	Low density fibreboard	12	250
M27	Gypsum plasterboard/ FR PUR foam core	13+87	PUR: 38
M28	Acoustic mineral fibre tiles	18	Wool: 220
M29	Textiles wall paper on calcium silicate board	CaSi: 10	CaSi: 875
M30	Paper-faced glass wool	100	18

Graphical correlations of the SBI Classes and the ISO results on time to flashover, time to peak heat release rate and peak heat release rate are shown in Figs. 4 and 5.

A ranking system using the FIGRA(ISO 9705) was used to compare with the Euroclasses [22] as:

- Euroclass A1: FIGRA(ISO 9705) < 0
- Euroclass A2: FIGRA(ISO 9705) ≤ 0.16
- Euroclass B: FIGRA(ISO 9705) ≤ 0.5
- Euroclass C: FIGRA(ISO 9705) ≤ 1.5
- Euroclass D: FIGRA(ISO 9705) ≤ 7.5
- Euroclass E and F: FIGRA(ISO 9705) > 7.5

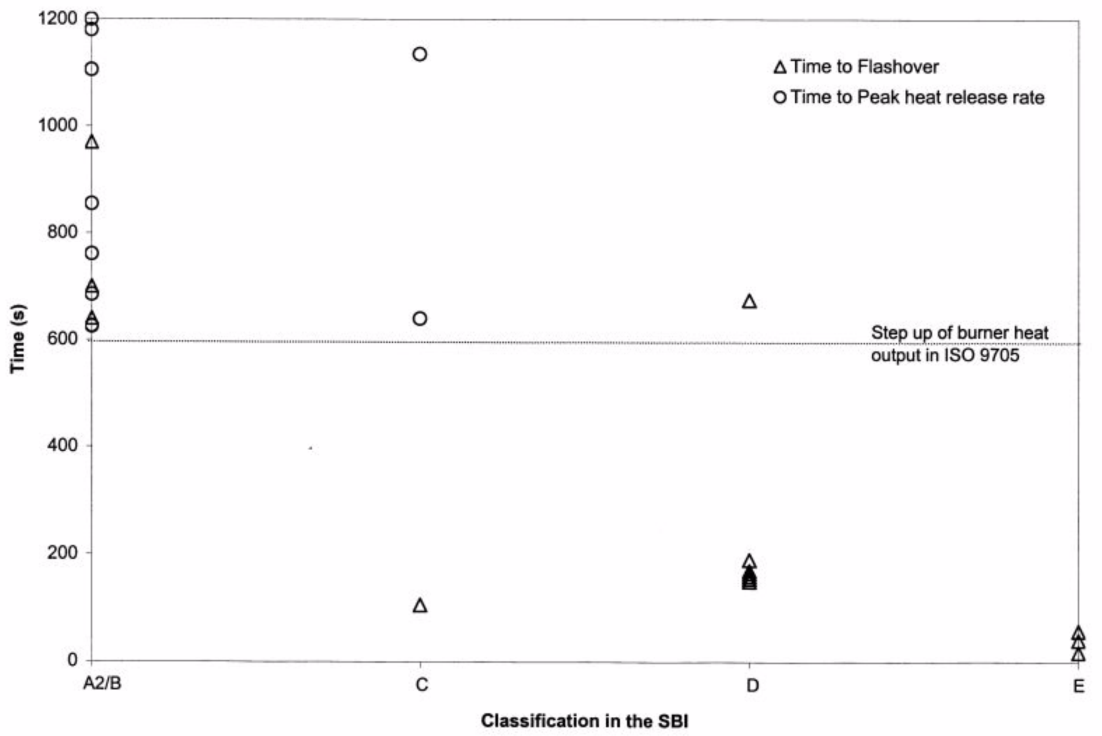

Fig. 4: Correlation of the classification in the SBI and results in ISO 9705

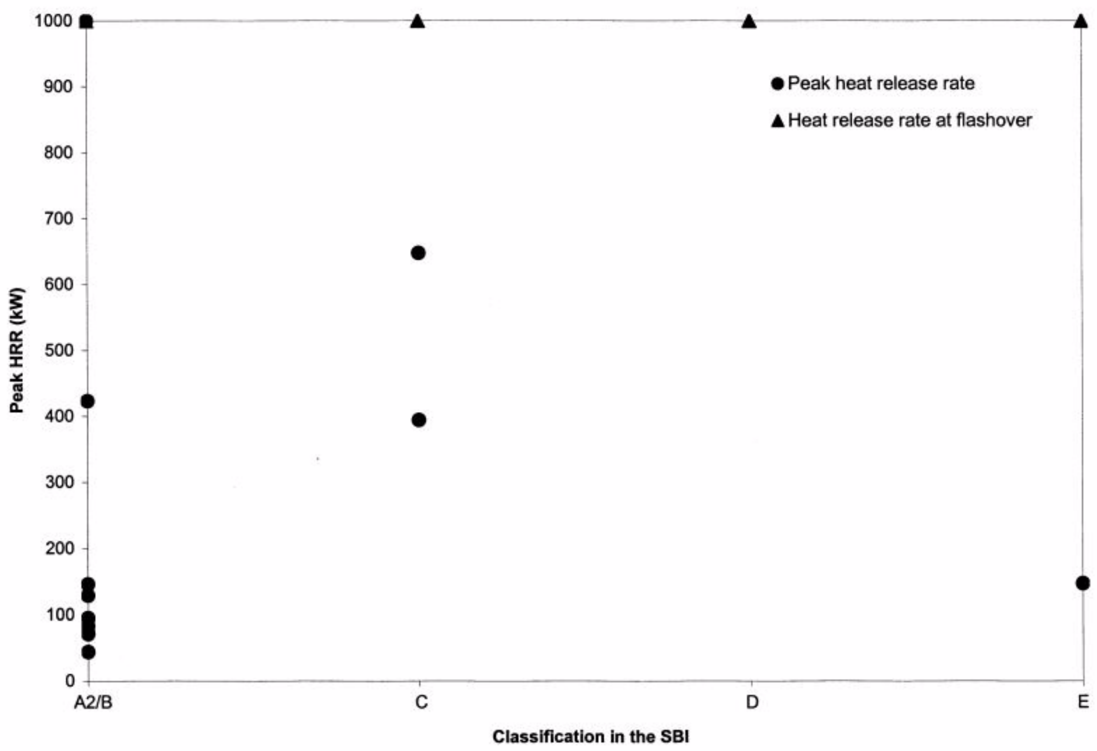

Fig. 5: Correlation of the classification in the SBI and peak heat release rate in ISO 9705

The FIGRA(ISO 9705) indices for the round robin results are also shown in Table 4. It was shown that the above ranking system is applicable to Classes B, D and E only. There are great discriminations for 0.5 ≤ FIGRA(ISO 9705) ≤ 1.5.

The FIGRA(ISO 9705) ranking was found to be agreed well with the ranking in time to flashover, which shows a fairly good correlation with the FIGRA in SBI as shown in Fig. 6.

Table 4: Comparison of SBI and ISO 9705 results and FIGRA rankings

Code	Euroclass [26]	SBI results [17]			ISO 9705 results [22]			
		$FIGRA_{0.2MJ}$ / Ws^{-1}	$FIGRA_{0.4MJ}$ / Ws^{-1}	THR_{600s} / MJ	Time to flashover / min:sec	Peak heat release rate / kW	Time to peak heat release rate / min:sec	FIGRA (ISO 9705) / Ws^{-1}
M01	A2/B	21	8	1	-	94	10:26	0.15
M28	A2/B	0	1	0.7	-	44	14:15	0.05
M02	B	81	73	5.9	-	129	12:41	0.17
M06	B	25	21	2.3	-	423	20:00	0.35
M08	B	16	6	0.8	-	71	10:25	0.11
M11	B	78	33	1.2	-	95	11:25	0.14
M13	B	9	0	0.8	-	83	10:25	0.13
M14	B	82	49	3.2	10:40	>1000	-	1.09
M15	B	16	14	1.9	11:40	>1000	-	1
M19	B	1	3	0.7	-	73	19:40	0.06
M21	B	21	11	1.3	16:10	>1000	-	0.72
M27	B	17	6	0.7	-	146	18:25	0.13
M05	C	681	681	15.1	1:46	>1000	-	8.5
M09	C	202	154	1.4	-	394	10:40	0.62
M29	C	162	108	1.9	-	648	18:55	0.57
M10	D	380	374	6.5	11:15	>1000	-	1.04
M12	D	440	440	15.7	2:50	>1000	-	5.3
M16	D	601	601	24	2:30	>1000	-	6
M20	D	381	381	20.1	2:45	>1000	-	5.5
M22	D	404	404	26.9	2:35	>1000	-	5.8
M23	D	399	399	21.7	2:40	>1000	-	5.6
M24	D	479	479	26.7	2:45	>1000	-	5.5
M25	D	436	436	33.4	3:10	>1000	-	4.7
M04	E	1869	1869	28.6	0:41	>1000	-	22
M07	E	1028	1027	17.2	-	147	4:25	0.55
M26	E	1103	1103	39.7	00:58*	>1000	-	16
M30	E	4073	3923	6.7	00:18*	>1000	-	50
M03	E/F	1375	1375	40.5	1:36	>1000	-	9.4

Note: $FIGRA_{0.2MJ}$ is the maximum of the quotient of heat release rate from the specimen and the time of its occurrence using a THR-threshold of 0.2 MJ.
$FIGRA_{0.4MJ}$ is the maximum of the quotient of heat release rate from the specimen and the time of its occurrence using a THR-threshold of 0.4 MJ.

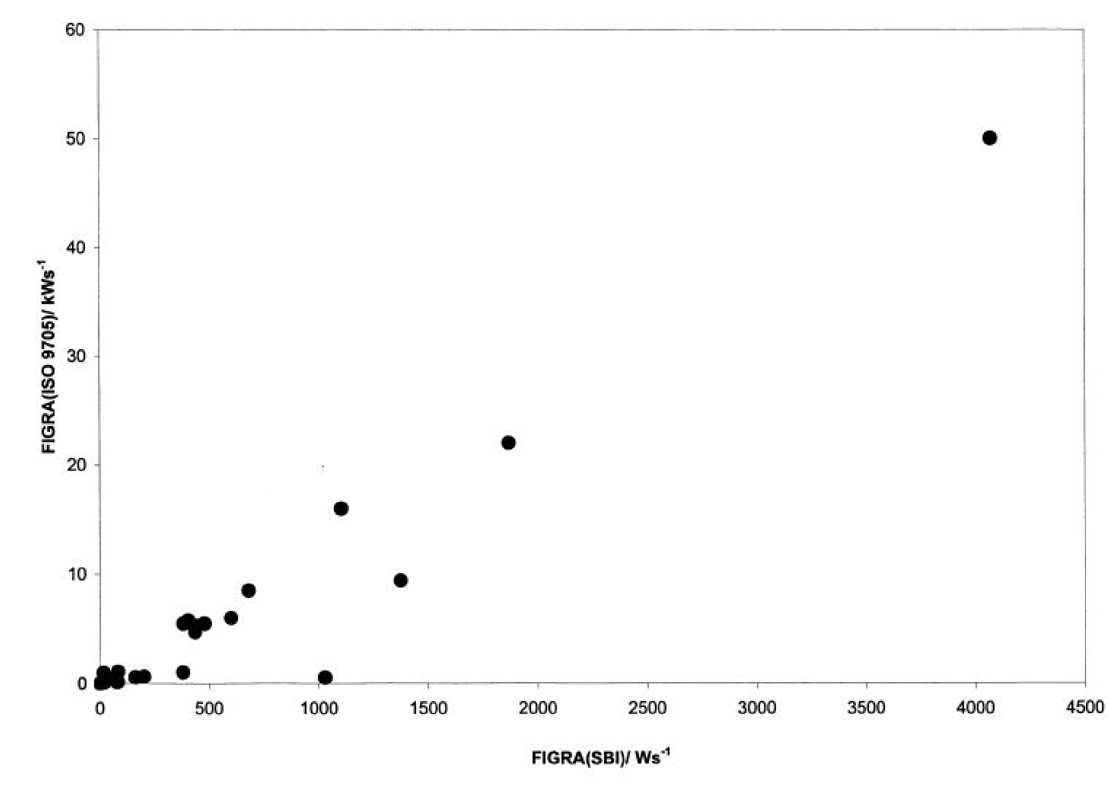

Fig. 6: Correlation of the FIGRA (ISO 9705) and FIGRA in the SBI

In the measurement of heat release rate and total heat release, good repeatability in the range of 3.7 to 13.4 and reasonable reproducibility ranging from 5.8 to 25.5 were obtained [17]. Repeatability is the precision under conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. Reproductibility is the precision under conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment [27]. Detailed data are shown in Table 5. Heat release rates with and without the inclusion of the standard burner were compared. It was observed that the overall repeatability and reproducibility results improved significantly with the contribution of the burner which gives out a controlled and steady heat output. In the measurement of lateral flame spread, reasonable repeatability and reproducibility were shown.

- RMB

Tests on 9 materials were carried out to find a relationship between the RMB and the ISO 9705 [14]. It was found that the correlation between the heat release rates from the RMB and the ISO 9705 was not good [25]. Even so, a very rough comparison was made [14] to derive a brief correlation between the results measured in the two tests.

- RMB: No flashover
  ISO 9705: No flashover
- RMB: Peak heat release rate < 100 kW
  ISO 9705: Time to flashover > 10 min
- RMB: Peak heat release rate > 200 kW
  ISO 9705: Time to flashover < 5 min

The results were tentatively [25] verified to relate the materials in Euroclasses A1, A2 and B which do not go to flashover in the first 10 minutes in the ISO 9705 into Class II in the Japanese system. Further studies should be carried out.

In the development of new fire standards in Japan, the SBI was recommended for studying smoke production and post-flashover properties only. Cone calorimeter was recommended [25] to be adopted in the new building standards in Japan due to its best correlation on heat release rate data with the ISO 9705. It was raised that there is no plan yet to use flame spread for classification [25].

Table 5: Repeatability and reproducibility data of the SBI round robin tests [17]

	Repeatability	Reproducibility
Peak heat release rate		
• With burner	4.6 % to 27.6 %	7.6 % to 55.3 %
	Mean: 13.4 %	Mean: 19.3 %
• Without burner	1.7 % to 13.2 %	1.9 % to 30.8 %
	Mean: 6.0 %	Mean: 8.7 %
Total heat release		
• With burner	5.2 % to 40.7 %	6.8 % to 59.9 %
	Mean: 16.8 %	Mean: 25.5 %
• Without burner	1.4 % to 12.2 %	2.5 % to 14.6 %
	Mean: 3.7 %	Mean: 5.8 %
Lateral flame spread		
• Reaching 250	9.2 % to 41.4 %	15.5 % to 135
	Mean: 22.1 %	Mean: 39.3 %
• Reaching 350	7.1 % to 28.7 %	15.7 % to 74.9 %
	Mean: 18.9 %	Mean: 35.2 %

8. CONCLUSION

At the moment, the Hong Kong government still sticks to the prescriptive fire tests. In assessing the flame spread properties of materials, only the bench-scale British Standard, BS 476: Part 7 is specified. This is an assessment based on the extent of lateral flame spread only. There are limitations in the testing environment, geometry and composition of materials. The UK has adopted the harmonized system of reaction to fire tests established by the European Union. The national British tests would be replaced by the new set of unified schemes. Further, in coping with the development of performance-based fire codes, there is a must for the local government to urgently consider reviewing the current regulatory tools and to move to the performance-oriented fire tests. There would be a revolution in fire standards in the local codes.

In this paper, two tests were reviewed. The SBI is the new unified European test and the RMB is a scaled model of the ISO 9705 developed in Japan and being further modified as an ISO standard. The cost are lower and there are less safety concern. The testing setup, testing environment and results were compared with the ISO 9705.

The SBI can be used to distinguish materials in several groups when comparing with the data on time to flashover in the ISO 9705, except for the Class C materials where more data are needed for further justification. As the RMB is under further development, more data would be available later for a more in-depth analysis.

At this point, defining a practical approach to assess flame spread is necessary. The Chinese, Taiwanese and Hong Kong government might work together to come up with a regional testing scheme, to maintain international trades with other countries and to remain competitive in the world market.

REFERENCES

1. C.W. Leung and W.K. Chow, "Review on four standard tests on flame spreading", International Journal on Engineering Performance-Based Fire Codes, Vol. 3, No. 2, pp. 67-86 (2001).
2. C.W. Leung and W.K. Chow, "Recommendation on assessing flame spreading of materials using ISO 9705", 2003 International Symposium of Fire Science and Fire-protection Engineering, Oct 2003, Beijing, China - Submitted for consideration to publish, May (2003).
3. British Standard BS 476, Fire tests on building materials and structure, Part 7: Method of test to determine the classification of the surface spread of flame of products, British Standards Institution, London, UK (1997).
4. Code of Practice for the Provision of Means of Access for Firefighting and Rescue Purpose, Building Authority, Hong Kong (1995).

5. Code of Practice for the Provision of Means of Escape in Case of Fire, Building Authority, Hong Kong (1996).

6. Code of Practice for Fire Resisting Construction, Building Authority, Hong Kong (1996).

7. Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment, Fire Services Department, Hong Kong Special Administrative Region (1998).

8. ISO 9705: 1993(E), Fire tests – Full-scale room test for surface products, International Standards Organization, Geneva, Switzerland (1996).

9. W.K. Chow, "Support on carrying out full-scale burning tests for karaokes", International Journal on Engineering Performance-Based Fire Codes, Vol. 3, No. 3, pp. 104-112 (2001).

10. British Standard BS EN 13823:2002, Reaction to fire tests for building products. Building products excluding floorings exposed to the thermal attack by a single burning item, British Standards Institution, London, UK (2002).

11. Certification of quasi-noncombustible materials and fire retardant materials, Notification No. 1321 of the Ministry of Construction, 3rd edition, The Building Center of Japan, Tokyo, Japan (1994).

12. British Standard BS EN 13501-1: 2002, Fire classification of construction products and building elements, Part 1: Classification using test data from reaction to fire tests, British Standards Institution, London, UK, 2002.

13. ISO/CD 17431, Fire tests – Reduced-scale model box test, International Standards Organization, Geneva, Switzerland.

14. M. Yoshida, Y. Hasemi, Y. Tanaike, S. Tasaka, F. Saito and J. Fangrat, "Comparative studies in the reduced-scale model box and the room corner test", Interflam '99, Vol. 1, pp. 23-33 (1999).

15. V. Babrauskas, "Redefining the value of π in the European Union, Editorial", Fire Safety Journal, Vol. 29, Editorial 2, pp. ix-x (1997).

16. P.V. Hees, T. Hertzberg and A.S. Hansen, "Development of a screening method for the SBI and room corner using the cone calorimeter", Nordtest project 1479-00, SP Report 2002:11, Fire Technology, SP, Swedish National Testing Institute, Sweden (2002).

17. "The SBI round robin report", Europa, European Union, http://europa.eu.int/comm/enterprise/construction/internal/essreq/fire/sbiround/sbirrrep.htm.

18. P.H. Thomas, "Testing products and materials for their contribution to flashover in rooms", Fire and Materials, Vol. 5, pp. 103-111 (1981).

19. British Standard BS EN ISO 1182:2002, Reaction to fire tests for building products. Non-combustibility test, British Standards Institution, London, UK (2002).

20. British Standard BS EN ISO 1716:2002, Reaction to fire tests for building products. Determination of the heat of combustion, British Standards Institution, London, UK (2002).

21. British Standard BS EN ISO 11925-2:2002, Reaction to fire tests. Ignitability of building products subjected to direct impingement of flame. Single-flame source test, British Standards Institution, London, UK (2002).

22. B. Sundstrom, P.V. Hees and P. Thureson, "Results and analysis from fire tests of building products in ISO 9705, the room/corner test", The SBI research programme, SP Report 1998:11, Fire Technology, SP, Swedish National Testing Institute, Sweden (1998).

23. J. Hietaniemi, E. Mikkola, B. Sundstrom, P. V. Hees, B. Kristoffersen and D. Bluhme, "Testing procedures for special construction products in the Euroclass system", Nordtest Project No. 1478-00, Nordtest, Finland, http://www.nordtest.org/projects/finalrep/1478-00.pdf (2000).

24. ISO 5660-1: 1993, Fire tests – Reaction to fire – Part 1: Rate of heat release from building products (cone calorimeter method), International Standards Organization, Geneva, Switzerland (1993).

25. B. Hedskog and F. Ryber, "The classification systems for surface lining materials used in buildings in Europe and Japan – a summary and comparison", Report 5023, Department of Fire Safety Engineering, Institute of Technology, Lund University, Lund, Sweden (1998).

26. A.S. Hansen, "Prediction of heat release in the single burning item test", Fire and Materials, Vol. 26, pp. 87-97 (2002).

27. ISO 3534-1: 1993 (E/F), Statistics – Vocabulary and symbols – Part 1: Probability and general statistical terms, International Standards Organization, Geneva, Switzerland.