

- Sprinkler C_C, a concealed sprinkler with glass bulb element and domed concealer plate, resulted in a thermal sensitivity rating of standard A response, in both favourable and unfavourable conditions.
- Sprinkler D_C, a concealed sprinkler with fusible link element, drop down deflector and flat concealer plate, resulted in a C factor 'off scale'. The theoretical (assuming a lower C factor, see 5.8.1) thermal sensitivity rating was standard B response in favourable conditions.
- Sprinkler F_C, a concealed sprinkler with fusible link element, drop down deflector, flat concealer plate and no vent holes, resulted in a thermal sensitivity rating of standard A response under favourable conditions. When tested under unfavourable conditions, including no positive pressure differential, the resulting thermal sensitivity rating was 'off scale'.
- Sprinkler G_C, a concealed sprinkler with fusible link element, drop down deflector and flat concealer plate, resulted in a thermal sensitivity rating of standard A response in both favourable and unfavourable conditions.
- All the maintainability scenarios tested using sprinkler E_C, resulted in a significant detrimental effect on the thermal sensitivity rating.
- The issue of whether the thermal sensitivity ratings determined in this study for concealed and recessed residential sprinklers are suitable for life safety applications could be considered by the relevant British Standards committee.

5.10 References for thermal sensitivity

1. British Standards Institution. Draft for Development DD 252: Components for residential sprinkler systems. Specification and test methods for residential sprinklers, July 2002.
2. Bill R G and Heskestad G, Plunge test procedures for recessed, flush and concealed sprinklers, Factory Mutual Research Technical report, February 1995.
3. Factory Mutual Research Corporation Approval Standard. Automatic Sprinklers for fire protection, Class Series 2000, May 1998.
4. Underwriters Laboratories Inc. UL 1626, Residential sprinklers for fire-protection service, 2001.
5. Loss Prevention Standard. LPS 1039: issue 5, Requirements and testing methods for automatic sprinklers, BRE Certification, 2002.
6. British Standards Institution. BS EN 12259: Part 1: 1999. Fixed firefighting systems – Components for sprinkler and water spray systems. Part 1 Sprinklers, incorporating Amendment Nos. 1 and 2 and Corrigendum No.1.
7. British Standards Institution. BS 9251 Sprinkler systems for residential and domestic occupancies – Code of Practice, January 2005.

5.9 Summary and conclusions of the wind tunnel work

The purpose of this stage of the project was to establish a suitable UK thermal sensitivity test for concealed and recessed residential sprinklers.

A new test has been specified and developed. The design has been based on DD 252 and previous experimental work from the USA and utilises a modified mounting plate and frame with appropriate instrumentation. An experimental matrix was devised and tests conducted that investigated the effect on the thermal response of sprinkler model, frame arm/deflector attachment pins orientation, recess distance, concealer plate retainer orientation (i.e. lug position), wind tunnel air temperature, wind tunnel air velocity and the pressure difference between the wind tunnel and the plenum box. Tests were also conducted that investigated the influence of some plausible maintainability scenarios on the thermal sensitivity of concealed residential sprinklers. One pendent, one recessed and five concealed residential sprinkler models were used.

The thermal sensitivity (C factor and RTI) and resulting classification of category have been calculated in accordance with the specifications of DD 252 and EN 12259-1.

For the conditions studied, the conclusions are as follows:

- A suitable thermal sensitivity test for evaluation of concealed sprinklers has been established for provision to the relevant British Standards committee for consideration in the development of residential sprinkler standards. Some improvements, modifications and required specifications have been identified.
- Sprinkler A_P, the pendent sprinkler, resulted in a thermal sensitivity rating of quick response under favourable conditions.
- Sprinkler E_C, a concealed sprinkler, resulted in a thermal sensitivity rating of special response in what were considered the most favourable conditions.
- In what was considered the most unfavourable conditions for sprinkler E_C, the RTI values were significantly increased from other tested conditions and resulted in a thermal sensitivity rating in the upper end of standard response A.
- In all other conditions tested, sprinkler E_C resulted in a thermal sensitivity rating of standard response A.
- Unfavourable frame arm orientation, maximum recess distance and unfavourable concealer plate position (at maximum recess distance) all had a detrimental effect on the thermal sensitivity of sprinkler E_C.
- The differences in determined RTI values for a given sprinkler due to different wind tunnel temperatures and velocities were found to be small.
- Higher pressure differentials between the tunnel and the plenum box, and therefore, higher vacuum flow rates were found to be beneficial in terms of concealed sprinkler thermal sensitivity.
- Sprinkler B_R, the recessed sprinkler, resulted in a thermal sensitivity rating of quick response at maximum recess distance and favourable frame arm orientation. With the frame arms rotated through 90 degrees and at maximum recess distance, the thermal sensitivity rating was determined as special response.

Sprinkler	Sprinkler details	Averaged RTI under 'favourable' conditions	Rank
A _P	Standard pendent, glass bulb	27.8	1
B _R	Recessed (at maximum recess distance), glass bulb	42.4	2
E _C	Concealed, domed concealer plate, glass bulb	71.9	3
C _C	Concealed, domed concealer plate, glass bulb	104.1	4
F _C	Concealed, flat plate, drop down deflector, fusible link, no vent holes	114.9	5
G _C	Concealed, flat plate, drop down deflector, fusible link	130.1	6
D _C	Concealed, flat plate, drop down deflector, fusible link	284.3	7

Table 6 Ranking order of RTI of residential sprinklers from wind tunnel tests

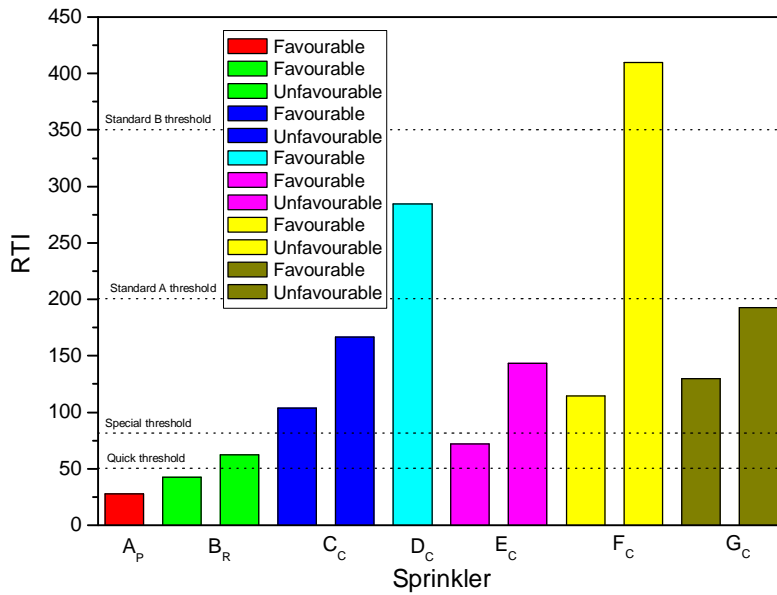


Figure 15 Comparison of average RTI values for sprinklers tested in the wind tunnel

Note: the tunnel conditions and sprinkler set-ups for these tests varied considerably and the terms 'favourable' and 'unfavourable' are used broadly

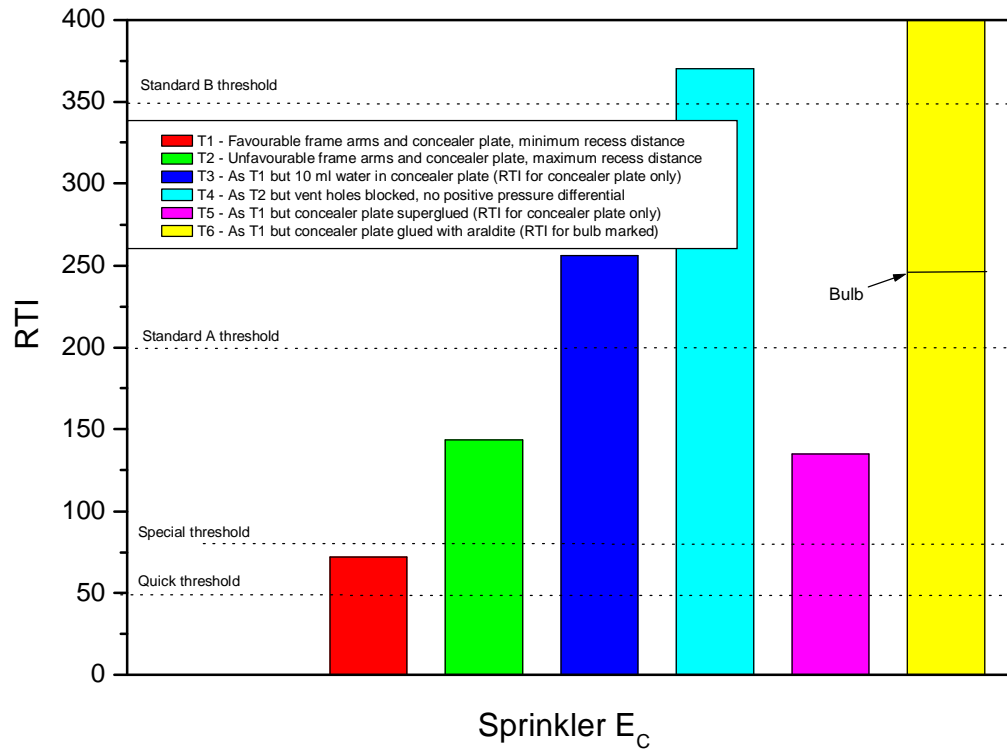


Figure 14 Bar chart showing the influence of plausible maintainability scenarios on the RTI of sprinkler E_C

5.8.5 Comparison of thermal sensitivity of tested sprinklers

One pendent, one recessed and five concealed heads were tested in the heated wind tunnel. Table 6 compares and ranks the averaged RTI's for the sprinklers tested in favourable conditions. Figure 15 displays the results graphically.

Test ¹	Sprinkler set-up details ²	Percentage increase in average RTI ^{3,4} (%)	Response category
1	Frame arms 'normal', minimum recess distance, favourable concealer plate/lug position and a nominal pressure difference between tunnel and plenum box of 1.3 Pa (considered most favourable conditions possible)	Result used as 'baseline'	Special
Deviation of sprinkler set-up from Test 1			
2	Frame arms rotated 90 degrees, maximum recess distance, unfavourable concealer plate retainer/lug position and a nominal pressure difference between tunnel and plenum box of 1.3 Pa (considered least favourable conditions possible)	99.7	Standard A
3	As Test 1, but with 10 ml of water placed in the concealer plate	256.1 ⁵	Standard B
4	As Test 2, but with the vent holes in the sprinkler cup housing blocked and no positive pressure differential between the tunnel and the plenum box	414.6	Off scale
5	As Test 1, but with the concealer plate retainer lugs superglued ⁶	87.8 ⁵	Standard A
6	As Test 1, but with the concealer plate retainer lugs glued with araldite	246.3 ⁷	Standard B
<p>Notes.</p> <p>¹ Nominal test numbers used for this section.</p> <p>² The wind tunnel conditions were set for all these tests at a nominal temperature of 135°C and nominal velocity of 2.5 m/s.</p> <p>³ A minimum of three tests were conducted with the set-up for Test 1 and 2 but only one for Tests 3, 4 and 5.</p> <p>⁴ The RTI was determined using Equations 1 and 2; the determined C factor for this sprinkler and that used in these calculations was 0.46 m/s^{1/2}.</p> <p>⁵ The RTI was calculated on the operation time of the concealer plate not on the sprinkler bulb.</p> <p>⁶ It was only possible to glue two of the three concealer plate lugs.</p> <p>⁷ The RTI was calculated on the operation time of the sprinkler bulb, the concealer plate did not operate</p>			

Table 5 Summary of tests to investigate influence of plausible maintainability scenarios on RTI of sprinkler E_c

These tests were designed to be demonstration tests and not a detailed study of these effects. The RTI for the three maintainability scenarios tested ranged from a percentage increase of 88 to 415 % when compared to the value determined under the most favourable conditions. These tests have demonstrated the potential for the thermal sensitivity of concealed sprinklers to be significantly affected detrimentally by maintainability issues. Figure 14 displays the results graphically.

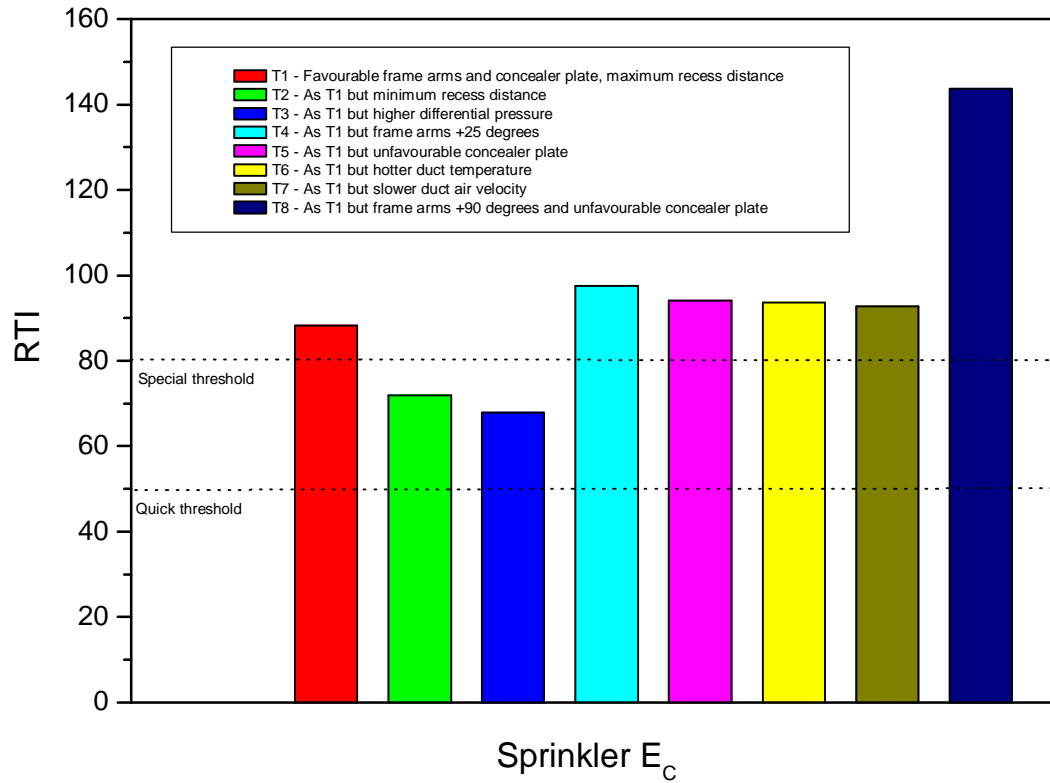


Figure 13 Bar chart showing the influence of various parameters on the RTI of sprinkler E_C

5.8.4 Influence of plausible maintainability scenarios on the RTI of sprinkler E_C

Wind tunnel tests were conducted with sprinkler E_C to investigate the influence of plausible maintainability scenarios on the RTI.

Table 5 is a summary table of the relevant tests.

It was found that the RTI (and therefore response time) was significantly reduced when the sprinkler was installed at the minimum recess distance compared with maximum recess distance. This difference changed the determined response category from standard A to special (see section 5.3 for thermal response categories). The sprinkler set-up details for the test at minimum recess distance were considered to be the most favourable.

There was also a significant reduction in RTI when the pressure differential between the tunnel and the plenum box was increased from ~1.3 to ~3.5 Pa. This difference changed the response category from standard A to special.

It should be noted that to achieve a positive pressure of 3.5 Pa it was necessary to use a number of pumps to extract air from the plenum box. Although the flow rate of extracted air was not measured, it may have resulted in a flow of air through the sprinkler that was not representative of flow through a sprinkler under fire test conditions.

With the sprinkler installed at maximum recess distance; rotating the frame arms 25 degrees, attaching the concealer plate in an unfavourable orientation, increasing the duct temperature and reducing the air velocity, resulted in higher RTI's when compared to the 'baseline' test. However, the percentage increase was a maximum of 10.5 % for these tests and did not alter the response category classification.

Again with the sprinkler installed at maximum recess distance, but also rotating the frame arms 90 degrees and attaching the concealer plate in an unfavourable orientation, the RTI was significantly higher at 62.6 % when compared to the 'baseline' test. The sprinkler set-up details for this test are considered to be the most unfavourable. Although the response category classification did not change, RTI was at the upper end of standard A. As the operation times for the concealer plates in these tests were comparable with those in the baseline tests, they demonstrate the influence that frame arm orientation can have on the thermal sensitivity of a glass bulb sprinkler at maximum recess distance. Similar comparable tests with sprinkler G_C suggests the effect of frame arm orientation may be less pronounced for fusible link sprinklers. However, this was not investigated further.

The determined RTI for what were considered most favourable and least favourable conditions for sprinkler E_C ranged from 72 to 144 ms^{1/2}, i.e. in these specific tests, the RTI determined for 'worst case' sprinkler installation was double that for 'best case'. Figure 13 presents the results graphically.

vacuum flow rates, are likely to increase the thermal sensitivity rating of concealed heads. Tight specifications of differential pressure and vacuum flow may be necessary to ensure consistent results can be achieved. These specifications could also significantly influence the RTI for any given sprinkler. An additional complication is that different sprinkler models will result in different differential pressures for different vacuum flow rates.

It was also found that the RTI for the concealed sprinklers tested increased significantly when tested in the most unfavourable conditions compared to the most favourable. Hence, a discussion of the most appropriate conditions for determination of thermal response rating of concealed sprinklers is necessary.

It is considered that a suitable thermal sensitivity test for evaluation of concealed sprinklers has been established. Possible improvements, modifications and required specifications have been identified.

5.8.3 Influence of parameter variation on the RTI of residential sprinkler E_C

Tests were conducted with sprinkler E_C to investigate the influence of various parameters on the RTI from wind tunnel tests. Concealed sprinkler E_C is a glass bulb sprinkler, rated at 68°C with a domed concealer plate, rated at 57°C.

Table 4 is a summary of the tests conducted.

Test ¹	Sprinkler set-up details ²	Percentage increase or decrease in average RTI ^{3,4} (%)	Response category
1	Frame arms 'normal', maximum recess depth ⁵ , favourable concealer plate/lug position and a nominal pressure difference between tunnel and plenum box of 1.3 Pa	Result used as 'baseline'	Standard A
Difference between this test and Test 1			
2	As Test 1, but at minimum recess distance	(-18.3)	Special
3	As Test 1, but at a higher nominal pressure differential of ~3.5 Pa	(-23.1)	Special
4	As Test 1, but frame arms rotated 25 degrees	+10.5	Standard A
5	As Test 1, but unfavourable concealer plate/lug position	+6.6	Standard A
6	As Test 1, but with a higher nominal tunnel duct temperature of 197°C	+6.0	Standard A
7	As Test 1, but with a slower nominal wind tunnel velocity of 1.75 m/s	+5.1	Standard A
8	As Test 1, but frame arms rotated 90 degrees and unfavourable concealer plate retainer/lug position	+62.6	Standard A
Notes.			
¹ Nominal test numbers used for this section.			
² The wind tunnel conditions were set for all these tests at a nominal temperature of 135°C and nominal velocity of 2.5 m/s unless stated otherwise.			
³ A minimum of three tests were conducted with each test set-up.			
⁴ The RTI was determined using the formulae described in Equations 1 and 2; the determined C factor for this sprinkler and that used in these calculations was 0.46 m/s ^{1/2} .			
⁵ It was not possible to consistently attach the concealer plate securely at the manufacturer's stated maximum recess distance. Therefore, these tests were conducted at approximately 2 mm from the stated maximum.			

Table 4 Summary of tests to investigate influence of parameter variation on sprinkler E_C thermal sensitivity

5.8 Discussion of wind tunnel tests

5.8.1 Suitability of ramp test for determination of C factor for concealed residential sprinklers

During testing of concealed sprinkler D_C, a ramp test resulted in a calculated C factor 'off scale'. This was probably partially due to a high mount/water bore temperature, in excess of 50°C at the time of operation. Mount temperatures in excess of 35°C for other concealed sprinklers may also have slightly 'skewed' the C factor determination. An improvement to the test method would be to maintain the mount temperature for prolonged exposure ramp tests. However, the C factor does have a smaller influence than 'time to operation' in the calculation formulae for determination of RTI from plunge tests.

The ramp test for concealed heads is not directly comparable to that for pendent heads. This is because with a concealed sprinkler, the test is in two distinct stages, firstly, until the operation of the concealer plate and secondly, until the operation of the sprinkler. In the ramp tests conducted in this study, the sprinkler concealer plate was initially predominantly exposed to the tunnel duct air (but with some positively pressurised flow through the air gap allowed by the concealer plate). On operation, the sprinkler element was exposed to a higher temperature than its nominal rating. Also, on concealer plate operation there was a change in pressure differential between the tunnel and the plenum box. It was not possible to quantify the resulting change in hot gas flow past the sprinkler element or its significance. This exposure is not consistent with the ramp test for pendent sprinklers upon which the formulae for determination of C factor was based. However, it is representative of real fire exposure sequences. All of the concealed sprinklers, except for sprinkler D_C, yielded results of C factor within the defined constraints, i.e. a maximum of 1 m/s^{1/2} for quick response sprinklers.

The influence of factors such as frame arm orientation/deflector attachment pins, recess distance, pressure differences and their effect on the C factor for any given concealed sprinkler was not investigated. Only 'favourable' sprinkler set-ups were tested during prolonged exposure ramp tests. Although only favourable conditions are used in the European standard for the evaluation of pendent sprinklers during ramp tests, it may be appropriate for concealed sprinklers to be tested in other conditions due to the significant number of additional variables involved.

5.8.2 Suitability of plunge test for determination of RTI for concealed residential sprinklers

Generally the results of wind tunnel plunge tests were consistent for any given set-up and proved reasonably repeatable. It was also concluded that the 'trap door' design for plunging sprinklers into the wind tunnel was appropriate as the sprinkler could be rapidly exposed with minor change in wind tunnel air temperature.

However, it was noted that there also seemed to be a general trend towards quicker response times as the test apparatus 'warmed' up over the period of any run of tests. Therefore, tighter specification of the variables involved would improve the test method. This could involve maintaining the mount temperature, plenum box air temperature and representative ceiling material temperature within specified limits.

Previous work and a limited number of tests in this study have demonstrated the importance of a positive pressure differential between the duct and the plenum box. However, the vacuum flow rate required to generate any given set pressure will vary between sprinkler models (and even with the same model, the tightness/looseness of fit of any given sprinkler). Tests also indicated that higher pressures, and higher

Test	Sprinkler	Nominal rating concealer plate /element (°C)	Test method	Frame arm/deflect or attachment pins (Degrees)	Recess distance	Concealer plate	Nominal air temperature (°C)	Nominal air velocity (m/s)	Measured maximum pressure difference (Pa)	Operation time concealer plate/ element (s)	C factor	RTI	Response category	
74	G _C	57 / 74	Plunge	0	Minimum	Favourable	57 + 1/min	1.0	1.61	15m14s / 40m14s	0.96	n/a	n/a	
75	G _C	57 / 74	Plunge	0	Minimum	Favourable	197	2.5	1.67	14.7 / 24.7	0.96	131.2	Standard A	
76	Repeat test 75									1.98	13.2 / 23.9	0.96	115.5	Standard A
77	Repeat test 76									1.24	18.5 / 30.6	0.96	143.6	Standard A
78	G _C	57 / 74	Plunge	+90	Maximum	Unfavourable	197	2.5	2.32	17.0 / 46.2	0.96	192.1	Standard A	
79	Repeat test 78									2.37	16.7 / 45.6	0.96	201.1	Standard B
80	Repeat test 79									2.29	14.2 / 40.2	0.96	185.3	Standard A
81	F _C	57 / 60	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	2.49	17m33s / 20m17s	0.71	n/a	n/a	
82	F _C	57 / 60	Plunge	0	Minimum	Favourable	197	2.5	1.47	11.7 / 17.8	0.71	123.0	Standard A	
83	Repeat test 82									1.37	5.2 / 13.5	0.71	102.5	Standard A
84	Repeat test 83									3.10	9.5 / 15.9	0.71	119.3	Standard A
85	F _C	57 / 60	Plunge	+90	Maximum	Unfavourable	197	2.5	-0	9.7 / 52.9	0.71	406.5	Off scale	
86	Repeat test 85									-0	9.9 / 53.7	0.71	413.0	Off scale
87	Repeat test 86									-0	8.8 / 52.4	0.71	410.6	Off scale
88	E _C	57 / 68	Plunge	0	Minimum	Favourable (but with 10 ml water)	135	2.5	1.71	53.3 / 56.9	0.46	256.0 (plate)	Standard B	
89	E _C (vent holes blocked)	57 / 68	Plunge	+90	Maximum	Unfavourable	135	2.5	-0	17.0 / 109.9	0.46	370.0	Off scale	
90	E _C	57 / 68	Plunge	0	Minimum	Favourable (2 lugs superglued)	135	2.5	1.31	36.3 / 40.3	0.46	135.0 (plate)	Standard A	
91	B _R	n/a / 68	Ramp	0	Maximum	n/a	68 + 1/in	1.0	-0	n/a / 29m9s	0.89	n/a	n/a	
92	B _R	n/a / 68	Plunge	0	Maximum	n/a	135	1.75	-0	n/a / 16.9	0.89	39.2	Quick	
93	Repeat test 92									-0	n/a / 19.8	0.89	43.4	Quick
94	Repeat test 93									-0	n/a / 20.5	0.89	44.5	Quick
95	B _R	n/a / 68	Plunge	+90	Maximum	n/a	135	1.75	-0	n/a / 26.2	0.89	55.4	Special	
96	Repeat test 95									-0	n/a / 33.2	0.89	71.0	Special
97	Repeat test 96									-0	n/1 / 30.8	0.89	66.0	Special
98	E _C	57 / 68	Plunge	0	Maximum	Favourable	135	1.75	3.29	12.6 / 24.1	0.46	69.9	Special	
99	Repeat test 98									3.45	10.0 / 23.1	0.46	71.9	Special
100	Repeat test 99									3.38	10.9 / 19.5	0.46	61.8	Special
101	E _C	57/68	Plunge	0	Minimum	Favourable	135	2.5	1.52	dno / -80	0.46	249 (bulb)	Off scale / Standard B	

Table 3 Wind tunnel tests conducted (continued)

Test	Sprinkler	Nominal rating concealer plate/ element (°C)	Test method	Frame arm/deflect or attachment pins (Degrees)	Recess distance	Concealer plate	Nominal air temperature (°C)	Nominal air velocity (m/s)	Measured maximum pressure difference (Pa)	Operation time of concealer plate/ element (s)	C factor	RTI	Response category	
58	E _c	57 / 68	Plunge	0	Maximum	Favourable	197	2.0	1.20	8.0 / 17.7	0.46	79.6	Special	
59	Repeat test 58									1.09	11.4 / 19.1	0.46	93.2	Standard A
60	Repeat test 59									1.13	8.8 / 17.4	0.46	85.2	Standard A
6	E _c	57 / 68	Plunge	0	Maximum	Favourable	135	2.5	1.49	14.7 / 34.4	0.46	94.0	Standard A	
7	Repeat test 6									1.16	17.0 / 35.1	0.46	99.1	Standard A
8	Repeat test 7									1.37	11.0 / 23.7	0.46	71.7	Special
9	E _c	57 / 68	Plunge	+25	Maximum	Favourable	135	2.5	1.42	14.0 / 35.6	0.46	104.0	Standard A	
10	Repeat test 9									1.32	9.8 / 27.9	0.46	81.2	Standard A
11	Repeat test 10									1.13	11.6 / 37.3	0.46	107.5	Standard A
12	E _c	57 / 68	Plunge	0	Minimum	Favourable	135	2.5	1.13	17.0 / 25.9	0.46	75.4	Special	
13	Repeat test 11									1.37	18.8 / 26.8	0.46	80.0	Special
14	Repeat test 12									1.07	11.3 / 19.5	0.46	60.2	Special
15	E _c	57 / 68	Plunge	0	Maximum	Unfavourable	135	2.5	1.56	14.0 / 31.0	0.46	98.4	Standard A	
16	Repeat test 15									1.34	11.8 / 26.4	0.46	84.3	Standard A
17	Repeat test 16									1.22	11.9 / 31.0	0.46	99.6	Standard A
18	E _c	57 / 68	Plunge	0	Maximum	Favourable	197	2.89	1.21	7.8 / 14.7	0.46	81.6	Standard A	
19	Repeat test 18									1.29	7.5 / 14.6	0.46	82.6	Standard A
20	Repeat test 19									1.39	12.9 / 19.7	0.46	116.7	Standard A
47	E _c	57 / 68	Plunge	+90	Maximum	Unfavourable	135	1.75	1.29	12.9 / 76.7	0.46	188.1	Standard A	
48	Repeat test 47									1.22	16.2 / 54.5	0.46	131.7	Standard A
49	Repeat test 48									1.12	17.2 / 57.5	0.46	140.6	Standard A
50	Repeat test 49									1.17	14.7 / 50.9	0.46	126.1	Standard A
51	Repeat test 50									1.23	14.7 / 53.4	0.46	131.2	Standard A
61	D _c	57 / 71	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	1.05	15m14s / 50m50s	2.37	n/a	n/a	
62	D _c	57 / 71	Plunge	0	Minimum	Favourable	135	1.75	1.13	26.2 / 7m46s	2.37	777.0	Off scale	
63	D _c	57 / 71	Plunge	0	Minimum	Favourable	197	2.89	1.46	13.3 / 79.9	2.37	432.6	Off scale	
64	D _c	57 / 71	Plunge	0	Minimum	Favourable	197	2.5	1.08	18.4 / 70.4	2.37	282.3	Off scale (Standard B)	
65	Repeat test 64									1.41	12.5 / 59.2	2.37	261.3	Off scale (Standard B)
66	Repeat test 65									1.53	11.0 / 64.7	2.37	309.2	Off scale (Standard B)
67	C _c	57 / 68	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	0.88	14m28s / 25m38s	0.52	n/a	n/a	
68	C _c	57 / 68	Plunge	0	Minimum	Favourable	135	2.5	2.30	24.0 / 33.3	0.52	112.6	Standard A	
69	Repeat test 68									2.21	23.2 / 30.5	0.52	98.9	Standard A
70	Repeat test 69									2.27	21.2 / 31.8	0.52	100.9	Standard A
71	C _c	57 / 68	Plunge	+90	Maximum	Unfavourable	197	2.5	2.46	14.5 / 31.9	0.52	166.3	Standard A	
72	Repeat test 71									1.97	13.3 / 28.3	0.52	155.9	Standard A
73	Repeat test 72									2.36	12.3 / 31.3	0.52	178.2	Standard A

Table 3 Wind tunnel tests conducted (continued)

Test	Sprinkler	Nominal rating concealer plate / element (°C)	Test method	Frame arm/deflect or attachment pins (Degrees)	Recess distance	Concealer plate	Nominal air temperature (°C)	Nominal air velocity (m/s)	Measured maximum pressure difference (Pa)	Operation time of concealer plate/ element (s)	C factor	RTI	Response category
55	A _P	n/a / 68	Ramp	0	n/a	Favourable	68 + 1/min	1.0	-0	n/a / 18m6s	0.56	n/a	n/a
56									-0	n/a / 16m35s	0.53	n/a	n/a
57									-0	n/a / 15m15s	0.49	n/a	n/a
21	A _P	n/a / 68	Plunge	0	n/a	n/a	135	1.75	-0	n/a / 12.3	0.53	29.1	Quick
22									-0	n/a / 12.0	0.53	28.9	Quick
23									-0	n/a / 11.1	0.53	26.6	Quick
24									-0	n/a / 10.8	0.53	27.3	Quick
25									-0	n/a / 10.7	0.53	27.1	Quick
1	A _P	n/a / 68	Plunge	0	n/a	n/a	135	2.5	-0	n/a / 12.7	0.53	34.5	Quick
2									-0	n/a / 10.1	0.53	29.5	Quick
3									-0	n/a / 12.0	0.53	34.5	Quick
4									-0	n/a / 10.8	0.53	31.9	Quick
5									-0	n/a / 10.6	0.53	31.2	Quick
38	E _C	57 / 68	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	1.03	15m40s / n/a	0.71	n/a	n/a
39									0.94	14m14s / n/a	0.68	n/a	n/a
40									0.96	13m3s / n/a	0.68	n/a	n/a
41	E _C	57 / 68	Ramp	0	Minimum	Favourable	68 + 1/min	1.0	0.38	n/a / 18m43s	0.79	n/a	n/a
42									0.32	n/a / 13m17s	0.46	n/a	n/a
43									0.38	n/a / 15m45s	0.62	n/a	n/a
44	E _C	57 / 68	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	0.99	17m/51s / 23m/43s	0.45	n/a	n/a
45									1.07	16m10 / 23m0s	0.43	n/a	n/a
46									0.93	11m59s / 23m38s	0.50	n/a	n/a
26	E _C	57 / 68	Plunge	0	Maximum	Favourable	135	1.75	1.14	22.8 / 44.1	0.46	102.7	Standard A
27									0.86	13.7 / 35.1	0.46	83.7	Standard A
28									1.11	19.1 / 37.3	0.46	92.1	Standard A
29	E _C	57 / 68	Plunge	+25	Maximum	Favourable	135	1.75	0.94	10.5 / 33.1	0.46	82.3	Standard A
30									1.09	15.7 / 30.7	0.46	78.4	Special
31									0.95	11.6 / 29.3	0.46	75.8	Special
32	E _C	57 / 68	Plunge	0	Minimum	Favourable	135	1.75	1.04	15.0 / 25.9	0.46	66.2	Special
33									1.11	11.4 / 23.5	0.46	58.8	Special
34									1.04	14.1 / 24.2	0.46	62.7	Special
52									1.15	18.8 / 29.2	0.46	71.7	Special
53									1.24	20.2 / 30.3	0.46	73.2	Special
54									1.22	14.4 / 23.6	0.46	57.4	Special
35	E _C	57 / 68	Plunge	0	Maximum	Unfavourable	135	1.75	1.07	14.7 / 43.0	0.46	110.0	Standard A
36									1.18	14.2 / 35.9	0.46	91.1	Standard A
37									1.18	13.3 / 29.8	0.46	75.4	Special

Table 3 Wind tunnel tests conducted



The BRE heated wind tunnel test arrangement



Pendent sprinkler prior to plunge test



Sprinkler under test



Pendent sprinkler after operation, viewed through window



Concealed head installed at maximum recess distance prior to attachment of concealer plate



Concealed head with concealer plate prior to test

Figure 12 Selected photographs taken during wind tunnel testing

Test set-up	Sprinkler	Test method	Frame arm orientation/deflector attachment pins (Degrees)	Recess distance	Concealer plate	Nominal air temperature (°C)	Nominal air velocity (m/s)	Nominal pressure difference (Pa)	Average RTI	Category
1	A _P	Ramp	0 (favourable)	n/a	n/a	68 +1/min	1.0	n/a	n/a	n/a
2	A _P	Plunge	0 (favourable)	n/a	n/a	135	1.75	n/a	27.8	Quick
3	B _R	Ramp	0 (favourable)	Maximum	n/a	68 + 1/min	1.75	n/a	n/a	n/a
4	B _R	Plunge	0 (favourable)	Maximum	n/a	135	1.75	n/a	42.4	Quick
5	B _R	Plunge	+90 (most unfavourable)	Maximum	n/a	135	1.75	n/a	62.5	Special
6	C _C	Ramp	0 (favourable)	Minimum	Favourable	57 + 1/min	1.0	1.33	n/a	n/a
7	C _C	Plunge	0 (favourable)	Minimum	Favourable	135	2.5	1.33	104.1	Standard A
8	C _C	Plunge	+90 (most unfavourable)	Maximum	Unfavourable	197	2.5	1.33	166.8	Standard A
9	D _C	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	1.33	n/a	n/a
10	D _C	Plunge	0	Minimum	Favourable	197	2.5	1.33	284.3	Standard B
11	E _C	Ramp	0 (favourable)	Minimum	Favourable	57+1/min	1.0	1.33	n/a	n/a
12	E _C	Plunge	0 (favourable)	Maximum	Favourable	135	2.5	1.33	88.3	Standard A
13	E _C	Plunge	+25 (unfavourable)	Maximum	Favourable	135	2.5	1.33	97.6	Standard A
14	E _C	Plunge	+90 (most unfavourable)	Maximum	Favourable	135	2.5	1.33	143.6	Standard A
15	E _C	Plunge	0 (favourable)	Minimum	Favourable	135	2.5	1.33	71.9	Special
16	E _C	Plunge	0 (favourable)	Maximum	Unfavourable	135	2.5	1.33	94.1	Standard A
17	E _C	Plunge	0 (favourable)	Maximum	Favourable	Hotter (197)	2.89	1.33	93.6	Standard A
18	E _C	Plunge	0 (favourable)	Maximum	Favourable	135	Slower (1.8)	1.33	92.8	Standard A
19	E _C	Plunge	0 (favourable)	Maximum	Favourable	135	1.75	Higher (3.5)	67.9	Special
20	F _C	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	1.33	n/a	n/a
21	F _C	Plunge	0	Minimum	Favourable	197	2.5	2.5	114.9	Standard A
22	F _C	Plunge	+90	Maximum	Unfavourable	197	2.5	0	410.0	Off scale
23	G _C	Ramp	0	Minimum	Favourable	57 + 1/min	1.0	1.33	n/a	n/a
24	G _C	Plunge	0	Minimum	Favourable	197	2.5	1.33	130.1	Standard A
25	G _C	Plunge	+90	Maximum	Unfavourable	197	2.5	1.33	192.8	Standard A

Note. n/a is not applicable

Table 2 Series of wind tunnel tests

5.5.3.7 Parameters that affect maintainability

The following parameters that affect maintainability were investigated; water in the concealer plate, glued concealer plate, blocking of the vent holes. These results are presented in section 5.7 and discussed in section 5.8.

5.6 Thermal sensitivity ratings

The thermal sensitivity ratings were determined using Equations 1 and 2 as described in section 5.3 and the response category classified in accordance with Figure 5.

The test requirements in DD 252 for pendent sprinklers include five plunge tests in any given condition and five prolonged exposure ramp tests. For this work, the minimum number of tests conducted for concealed and recessed heads was three plunge and one ramp test and the maximum number was six plunge and three ramp tests.

5.6.1 Experimental procedure for each test

The experimental procedure for each test was as follows:

- The required wind tunnel conditions were established and allowed to stabilise with the 'dummy' trap door in place
- The residential sprinkler test specimen was installed at the required recess distance, orientation, etc
- 40 ml of water was added to the sprinkler bore
- The sprinkler concealer plate was installed, where applicable
- The evacuation pump was turned on at the required setting, where applicable
- The instrumentation was checked and data acquisition started
- The dummy trap door was opened and replaced with the modified mounting plate containing the sprinkler test specimen, as quickly as possible
- A stopwatch was started as soon as the sprinkler was exposed to wind tunnel conditions and used to measure the time to concealer plate operation, where applicable, and sprinkler element operation
- All the test details were recorded.

5.7 Results of wind tunnel tests

Table 2 contains a summary of the key results.

Figure 12 shows selected photographs taken during wind tunnel testing.

Table 3 details a full list of all the tests conducted and the sprinkler operation times.

5.5.3.6 Pressure difference between wind tunnel and mounting plate plenum box

The pressure difference between the wind tunnel and the mounting plate plenum box applies only to the concealed residential sprinklers. Previous work has shown the importance of a positive pressure differential between the wind tunnel and the mounting plate plenum box for determining the thermal sensitivity of concealed sprinklers. To achieve this positive pressure, the plenum box was evacuated using an air pump. It should be noted that the concealer plate design and the depth of the air gap between concealer plate retainer and concealer plate vary for different sprinkler models. Therefore, for maintaining a set pressure difference for wind tunnel testing, for any given set of conditions, the evacuation rate will vary for different sprinkler models. Also, for any given sprinkler, the installation and snugness/looseness of fitting of the concealer plate will influence the pressure differential.

Measurements of ceiling pressure were made during the stylised fire tests. Tests were conducted to investigate the influence of the applied positive pressure. Values of pressures tested during wind tunnel testing were representative of the measured values taken from the fire tests. In addition, some tests were conducted with no positive pressure applied.

It was noted during testing that it was difficult to maintain a consistent positive pressure. The test method required the evacuation pump to be turned on a long time prior to a test. However, when a test started and a sprinkler was exposed to the wind tunnel conditions, there was a gradual increase in pressure differential. When the concealer plate operated, there was a quick drop in pressure to a lower, still positive, value. Therefore, a flow of hot air through the vented sprinkler recessed cup was maintained. Figure 11 shows a typical graph of pressure difference between the wind tunnel and plenum box against time.

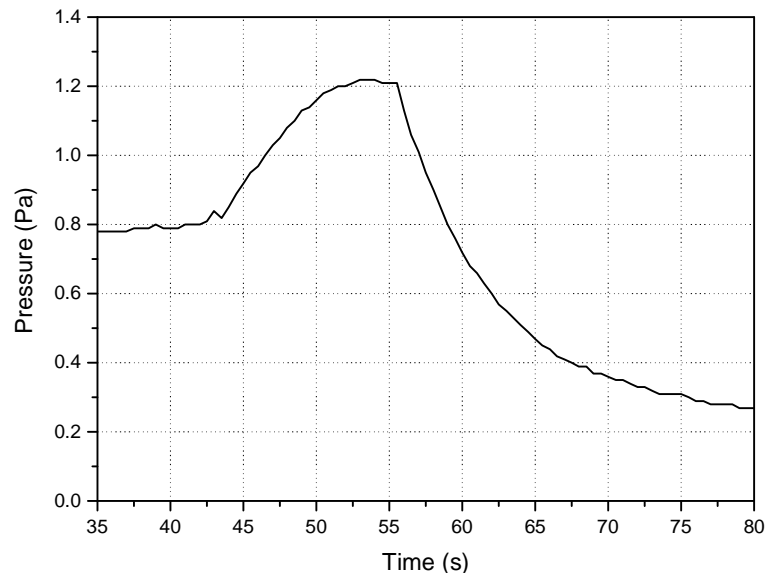


Figure 11 Typical pressure difference between wind tunnel and plenum box against time

5.5.3.2 Recess distance

All of the concealed and recessed sprinkler models investigated in this study had maximum and minimum recess distance details stated by the manufacturer on their relevant data sheets.

The depth of the sprinkler response element below (or above) ceiling level depends on the recess depth at which the sprinkler is installed. It was assumed that this recess would have an influence on the thermal response of the sprinkler and that the conditions could be considered favourable and unfavourable at minimum and maximum recess distances, respectively. Tests were conducted at the manufacturer's stated maximum and minimum recess distances.

5.5.3.3 Concealer plate retainer orientation and lug position

Concealer plate retainer orientation and lug position applies only to concealed sprinkler heads. All of the concealed heads tested had a concealer plate assembly that attached to the sprinkler housing. The concealer plate assembly consisted of a concealer plate retainer that is securely attached to the sprinkler recessed cup, with a plate attached by solder joints to three 'lugs' that allow the plate to fall away when operated. The width, depth and spacing of the lugs varied between sprinkler models. The depth of the lugs determined the air gap between the retainer and the plate. This air gap is important as it allows a flow of hot gases through the sprinkler assembly when subjected to a positive pressure. The concealer plates were also 'spring loaded' to aid separation of the plate and retainer upon melting of the solder. This was achieved either by a small spring clip or a thin metal sheet inserted between the plate and retainer that applied a small downward force, depending on the sprinkler model. The spring clip applied a force in one position, whilst the thin metal sheet applied a force at three locations. The nominal temperature rating of all the concealer plates tested was 57°C.

A test result during the stylised fires indicated that the position of the concealer plate retainer lugs may influence the water distribution characteristics of any given sprinkler head, particularly when installed at maximum recess distance. It was also assumed that the lug position may have a small influence on the thermal sensitivity when installed at maximum recess distance. Conditions were considered favourable when the lug was positioned so there was no direct obstruction to the flow of hot air to the sprinkler response element and unfavourable when there was.

5.5.3.4 Wind tunnel air temperature

The European standard and DD 252 specify wind tunnel air temperatures for testing pendent sprinkler heads. The temperature at which a test is conducted will depend on the response category classification of the sprinkler head. Tests were conducted to investigate whether different wind tunnel air temperatures influenced the calculated RTI of a given sprinkler head.

5.5.3.5 Wind tunnel air velocity

The European standard and DD 252 specify wind tunnel air velocities for testing pendent sprinkler heads. The velocity at which a test is conducted will depend on the response category classification of the sprinkler head. Tests were conducted to investigate whether different wind tunnel air velocities influenced the calculated RTI of a given sprinkler head.

5.5.2 The series of tests

Table 2 shows the series of wind tunnel tests carried out, excluding the maintainability scenarios. A series of over one hundred wind tunnel tests was carried out to examine the effect of varying parameters on the thermal performance of concealed and recessed residential sprinklers.

5.5.3 Parameter variation

To evaluate the new test and to examine the effect of various parameters on the thermal response of concealed sprinklers, tests were initially carried out on a single selected concealed sprinkler, sprinkler E_C. This sprinkler has a vented cup, a domed concealer plate rated at 57°C and a glass bulb rated at 68°C. The effect of varying the following parameters on the thermal response for this sprinkler was examined:

- Frame arm/deflector attachment pins orientation
- Recess distance
- Concealer plate retainer orientation (lug position)
- Wind tunnel air temperature
- Wind tunnel air velocity
- Pressure difference between wind tunnel and mounting plate plenum box
- Parameters that affect maintainability, e.g. water in the concealer plate, glued concealer plate, blocking of the vent holes.

Following these tests, sprinklers B_R, C_C, D_C, F_C and G_C were tested to determine their thermal response for a single combination of parameters.

Sprinkler A_P, a pendent sprinkler, was tested using the modified mounting plate but with the DD 252 wind tunnel arrangement, for comparison.

Parameter variation is described, as follows.

5.5.3.1 Frame arm/deflector attachment pins orientation

The previous work by FMRC had shown that frame arm/deflector attachment pins orientation can have a significant influence on the thermal response of a sprinkler. Tests were conducted in what were considered to be favourable and unfavourable orientations to the flow of hot air in the wind tunnel. Favourable conditions were understood to be when the frame arms/deflector attachment pins were orientated parallel to the width of the wind tunnel. The most unfavourable conditions were considered to be when orientated parallel with the flow of hot air and rotated 90 degrees from the favourable position. Tests were also conducted at an angle of 25 degrees from the favourable position. These are the 'unfavourable' conditions tested as for standard pendent sprinklers in accordance with DD 252.

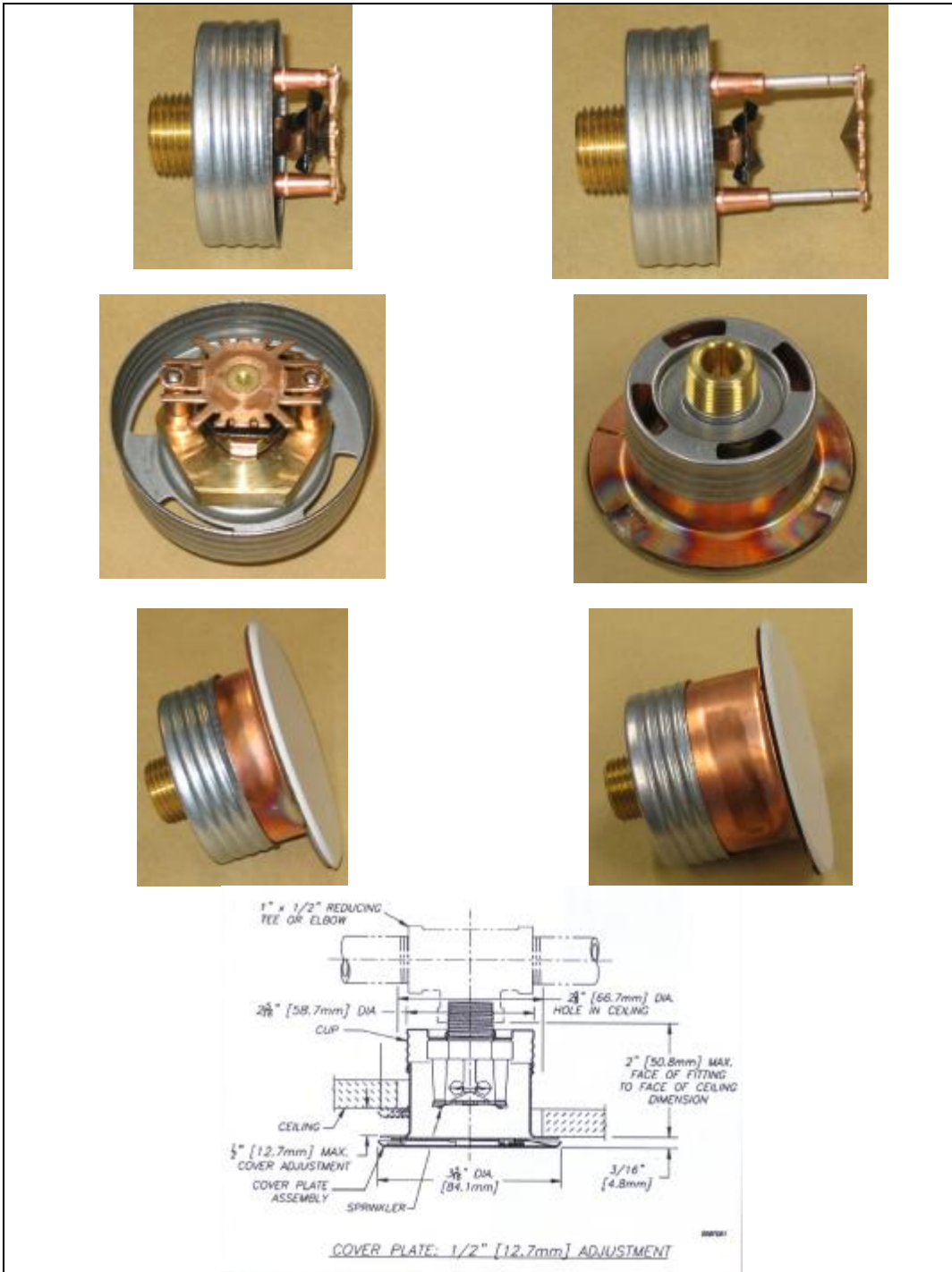


Figure 10 Photographs and schematic of sprinkler G_c

Sprinkler ¹	Type	k factor UK (K factor US)	Nominal operating temperature of sprinkler (concealer plate) (°C) (°C)	Details of concealer plate and recess cup	Manufacturer's recommended recessing details	
					Maximum	Minimum
A _P	Pendent	71 (4.9)	68 (not applicable) glass bulb	Not applicable	Not applicable	Not applicable
B _R	Recessed	62 (4.3)	68 (not applicable) glass bulb	Not applicable	Deflector 41 mm below ceiling	Deflector 22 mm below ceiling
C _C	Concealed	70 (4.9)	68 (57) glass bulb	Domed plate, vented cup	Concealer adjustment of 12.7mm	Concealer adjustment of 4.7mm
D _C	Concealed	60.5 (4.2)	71 (57) solder link	Flat plate, vented cup	Deflector 12.7mm below ceiling	Deflector 25.4mm below ceiling
E _C	Concealed	71 (4.9)	68 (57) glass bulb	Domed plate, vented cup	Deflector 9.5mm below ceiling	Deflector 22.2mm below ceiling
F _C	Concealed	59 (4.1)	60 (57) solder link	Flat plate, unvented cup	Distance between ceiling and sprinkler thread fitting of 65mm	Distance between ceiling and sprinkler thread fitting of 52.4mm
G _C	Concealed	62 (4.3)	74 (57)	Flat plate, vented cup	Concealer adjustment of 12.7mm	Concealer adjustment of 4.7mm

Note 1. P denotes pendent, R denotes recessed and C denotes concealed.

Table 1 Residential sprinklers chosen for wind tunnel tests

Figure 10 shows photographs of sprinkler G_C. Photographs of sprinklers A_P to F_C are included in Section 3: Stylised fires.

5.4.4 Advantages of wind tunnel for thermal sensitivity measurements

Some advantages of using a heated wind tunnel for thermal sensitivity measurements for concealed and recessed residential sprinklers when compared to full scale fire testing are as follows:

- Cheaper, quicker and cleaner
- Consistent approach as pendant sprinkler heads are tested using a wind tunnel in the European standard
- Research has demonstrated that it is possible to achieve good correlation with fire test results
- Repeatability can be readily investigated
- Flexibility, it is easy to change the test parameters if necessary.

5.5 Experimental method

The FMRC method uses the same equation as Equation 2 for calculation of RTI but does not use Equation 1 or the prolonged exposure ramp test to determine the Conductivity, C factor. Only plunge tests are used. The approach used for this work incorporated a prolonged exposure ramp test to determine the C factor for a given sprinkler. The C factor was determined in a test where the sprinkler was exposed in what were considered favourable conditions. However, it should be noted that this C factor was used to determine the RTI of any given sprinkler from plunge tests whether it was tested in favourable or unfavourable conditions.

5.5.1 Sprinklers tested

Table 1 details the sprinklers that were selected and used in the thermal sensitivity test series.

The wind tunnel and the mounting plate arrangement were instrumented to enable measurements of the following:

- Pressure difference between the plenum and the tunnel test section below (initial set value)
- Mount temperature (temperature of water in the sprinkler bore)
- Tunnel air temperature
- Tunnel air velocity
- Ambient temperature
- Plenum box air temperature
- Plenum box external wall temperature
- Operating time of sprinkler from start of plunge.

These parameters were monitored, where appropriate, for the duration of each test and the data recorded directly to a computer.



Figure 9 Instrumented modified mounting plate

5.4.2 Modified mounting plate and frame arrangement

A design was developed for a modified mounting plate and frame for the BRE heated wind tunnel that would enable evaluation of the thermal response of concealed and recessed sprinkler heads. Figure 8 is a schematic drawing which shows the outline design.

The metal frame was fixed in the wind tunnel opening and was secured to two trap doors. The hinged trap doors allowed two alternative plate arrangements to be placed in the wind tunnel opening, one after the other. One of the trap doors was a plate which maintained a smooth surface on the ceiling in the tunnel and was used to establish the required starting wind tunnel conditions. The other trap door housed the sprinkler under test and was used to expose the sprinkler to gas flow conditions. The sprinkler body was contained within the plenum box attached to the steel cover plate. The plate surface material of this trap door in contact with the wind tunnel was calcium silicate board. The sprinkler mount temperature was not controlled.

The salient features of the mounting plate are:

- Sprinkler head specimen mounted inside a closed plenum attached to a plate simulating a ceiling attached to the BRE heated wind tunnel
- Allows installation of sprinkler specimens in accordance with manufacturer's recommended practice
- The plate accommodates a variety of concealed and recessed sprinkler models
- The plenum was evacuated via a port to enable a positive pressure difference between the tunnel section underneath and the box, thus generating a flow of hot gases from the tunnel into the plenum. The FMRC research has shown that this is representative of room fire tests and real fires.

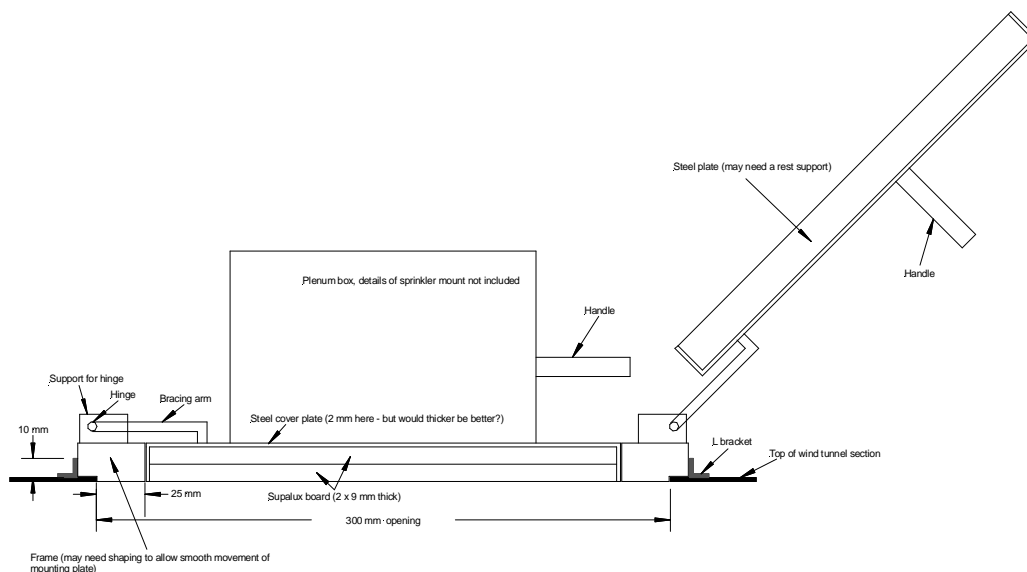


Figure 8 Side view of design of new mounting plates arrangement

5.4.3 Instrumentation

5.4 Thermal sensitivity apparatus

5.4.1 The experimental facility

The BRE heated wind tunnel is shown in Figure 6. Figure 7 shows the top of the wind tunnel test section with the cover in place and the sprinkler test assembly resting on top in preparation for testing fully exposed pendent sprinklers to BS EN 12259-1.



Figure 6 BRE heated wind tunnel



Figure 7 BRE mounting plate for EN 12259-1 standard thermal sensitivity test

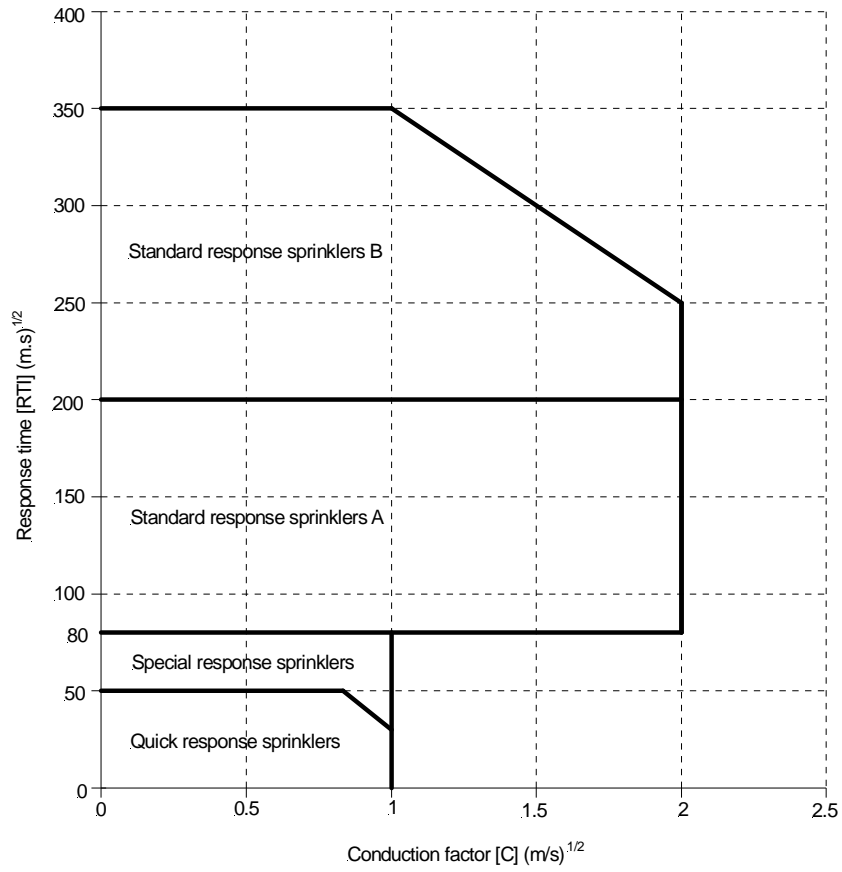


Figure 5 RTI and Conductivity factor limits for thermal sensitivity response classification

where:

ΔT_g is the actual or air temperature in the test section minus the mount temperature (T_m) at the time the sprinkler operates ($^{\circ}\text{C}$)

ΔT_{ea} is the mean operating temperature of the sprinkler minus the mount temperature at the time the sprinkler operates ($^{\circ}\text{C}$)

u is the actual gas (or air) velocity in the test section at the time the sprinkler operates (m/s).

RTI is obtained from plunge tests and the value of C obtained from the prolonged exposure ramp tests.

The plunge test involves five sprinkler specimens in favourable and then unfavourable orientations. Each sprinkler specimen is plunged into the heated wind tunnel air flow until operation. The air flow is set to a constant velocity and temperature according to operating temperature and thermal response category. The temperature of the water in the sprinkler waterway is kept constant throughout the test at $(30 \pm 2)^{\circ}\text{C}$.

The wind tunnel air temperature and velocity, sprinkler mount temperature, and the time between the plunging of sprinkler into the wind tunnel and sprinkler operation are recorded. Equation 2 is used to calculate the RTI for each test.

$$\text{RTI} = \left[\frac{-t_r \sqrt{u}}{\ln \left\{ 1 - \Delta T_{ea} (1 + C / \sqrt{u}) / \Delta T_g \right\}} \right] (1 + C / \sqrt{u}) \quad (\text{Equation 2})$$

where:

t_r is the response time of the sprinkler (s)

u is the actual gas or air velocity in the test section at the time the sprinkler operates (m/s)

ΔT_{ea} is the mean operating temperature of the sprinkler minus the mount temperature, at the time the sprinkler operates ($^{\circ}\text{C}$)

ΔT_g is the actual or air temperature in the test section minus the mount temperature (T_m), at the time the sprinkler operates ($^{\circ}\text{C}$)

C is the conductivity factor (m/s)^{1/2}

ln is the natural logarithm.

In BS EN 12259-1, there are four categories of thermal response of sprinklers: quick, special, standard response A and standard response B. BS 9251⁷ specifies 'quick response' in terms of thermal sensitivity rating for residential sprinklers. Figure 5 shows the RTI and C limits for thermal sensitivity response classification. For the unfavourable orientation (+25 degrees frame arm rotation), the average value of RTI must be less than 110% of these limits.

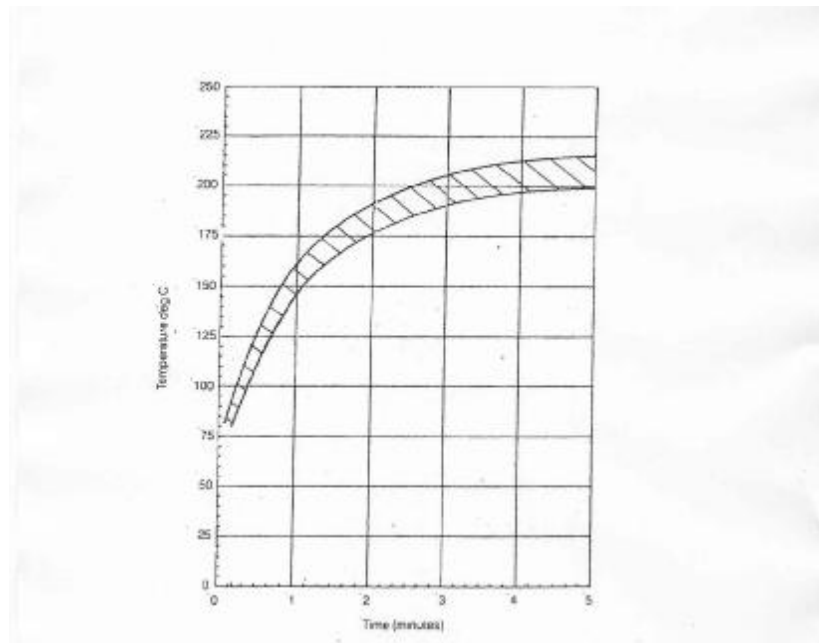


Figure 4 Temperature time relationship for LPS1039 room response test

5.3 Thermal sensitivity of pendent residential sprinklers

The method for determining the thermal sensitivity of pendent sprinkler heads in the UK and Europe is well established. In the European sprinkler components standard BS EN 12259-1⁶ and in the British Standard Draft for Development DD 252, a heated wind tunnel is used to determine the Response Time Index, RTI and the Conductivity factor, C. These parameters vary according to the orientation of the sprinkler relative to the gas flow.

C is obtained from a prolonged exposure ramp test for five conditioned specimens in the standard orientation. The test involves increasing the wind tunnel air stream temperature, starting at the nominal operating temperature of the sprinkler, by 1°C per minute until the sprinkler operates. The mount temperature is maintained at $(30 \pm 2)^\circ\text{C}$ for the duration of the test. On sprinkler operation, the mount temperature, wind tunnel air temperature and velocity are recorded.

Equation 1 is used to calculate the mean value of C from the five tests.

$$C = \left(\Delta T_g / \Delta T_{ea} - 1 \right) u^{1/2} \quad (\text{Equation 1})$$

Prior to the start of the test the room is preconditioned to $(30 \pm 5)^{\circ}\text{C}$ with a ceiling structure temperature of between 25°C and 40°C , and the specimens are preconditioned to $(20 \pm 5)^{\circ}\text{C}$ for at least 24 hours.

The specimen is installed, the burner ignited, and the time of operation recorded. For concealed sprinklers, the time for detachment of the concealer plate is also recorded.

Sprinklers should operate within the statistical limits of times specified in the following table.

Sprinkler nominal temperature rating ($^{\circ}\text{C}$)	Statistical limit of operating times* (s)
≤ 78	170
≤ 79	212
80 – 100	285

*Statistical limit is calculated using:

$$\bar{C} + 3.47^J n$$
 \bar{C} = the arithmetic mean response time of specimens tested
 $^J n$ = standard deviation for specimens tested
 3.47 = constant, used where 10 specimens are tested

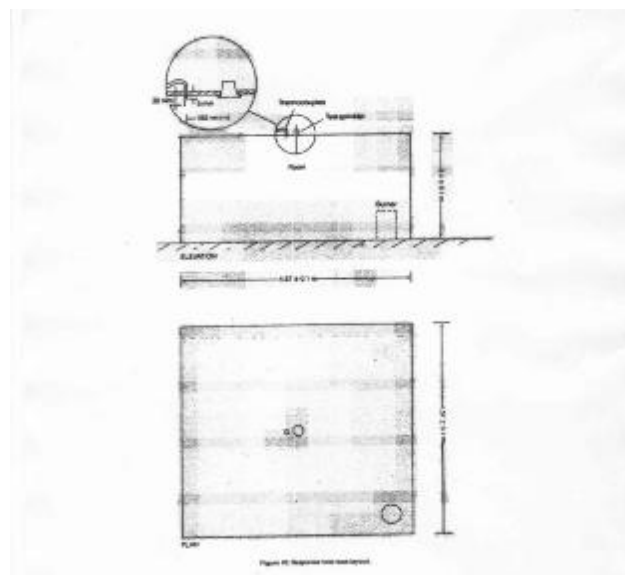


Figure 3 Test room details for LPS 1039 room response test

5.2.2 Review of Underwriters Laboratories room heat test

Underwriters Laboratories standard UL 1626 uses a room heat test to evaluate the thermal sensitivity of all types of residential sprinklers⁴.

The sprinkler under test is mounted on a ceiling or a wall of a closed 4.6 m by 4.6 m room with a 2.4 m high ceiling. The sprinkler inlet waterway is filled with water having a temperature of $(21 \pm 1.6)^{\circ}\text{C}$. The water is pressurised to 31 ± 3.4 kPa.

The fire source is a 0.305 m by 0.305 m square sandbox burner 0.305 m high located in one corner of the room with a flow of natural gas of $14.6 \text{ m}^3/\text{hour}$. A pendent, upright, or ceiling type sprinkler is installed along a diagonal line on the ceiling at a distance of 5.1 m from the corner of the room where the sand burner is located. A sidewall sprinkler is installed on the midpoint of a wall opposite the corner having the sand burner. The test is started when the ambient temperature is $(31 \pm 1)^{\circ}\text{C}$, as measured in the centre of the room, 254 mm below the ceiling. The gas burner is ignited, and the operation time of the sprinkler is recorded.

Ten sprinklers of each type are installed in a test room in specified positions and orientations, according to type.

A recessed or concealed sprinkler that is vented is installed and tested in an unblocked manner i.e. that will not inhibit airflow through the escutcheon. A recessed or concealed sprinkler that is unvented is installed and tested in a blocked manner i.e. that will inhibit airflow through the escutcheon by placing a 914 mm by 394 mm by 203 mm 'R-25' fibreglass insulating 'batt' over the sprinkler. The insulation is to be installed in a simulated wood joist channel 914 mm by 406 mm by 254 mm. A 38.1 mm by 89 mm board is secured to the inside top of each channel end over each insulation end to help secure the insulation end in place.

Each residential sprinkler tested should have an operating time of 75 s or less.

There is an additional requirement that a certain number of sprinkler specimens following heat and corrosion exposure tests should have a mean time operating time equal to or less than a 1.30 multiple of the mean operating time of the sprinklers which have not been exposure tested.

5.2.3 Loss Prevention Standard response test

Loss Prevention Standard 1039: issue 5⁵ contains a response test for ceiling flush, recessed and concealed sprinklers which involves a room fire test. This test was originally developed in the late 1980s for the use of these pattern sprinklers in offices. It was not developed as a ranking test but was used for approval purposes. The limits of operating times required are based on the slowest response pendent sprinklers approved in the late 1980s. Since then, bulb technology has changed, thermal response has improved and the requirements are out of date. Consequently, the test has fallen into disuse.

The sprinkler under test is installed in a ceiling panel in the centre of a closed room with floor dimensions of 4.57 m by 4.57 m ± 0.1 m and ceiling height of (2.4 ± 0.1) m, see Figure 3. The heat source is a propane gas pot burner, positioned in a corner with its centre 0.45 m ± 25 mm from two adjacent walls and its top surface 0.56 m ± 25 mm above the floor. Adequate ventilation is provided for the burner.

The room temperature is monitored 0.180 m from the centre of the room and 30 ± 2 mm below the ceiling. For the duration of the test, the room temperature at the measuring point follows a specified time/temperature curve, see Figure 4. The temperature is also monitored (5 ± 1) mm below the ceiling.

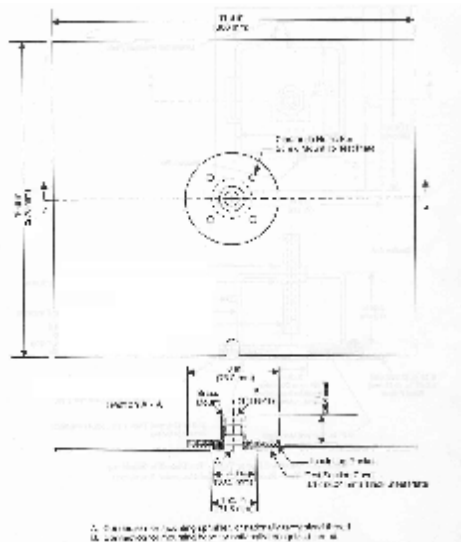


Figure 1 FMRC standard plunge tunnel test mounting plate

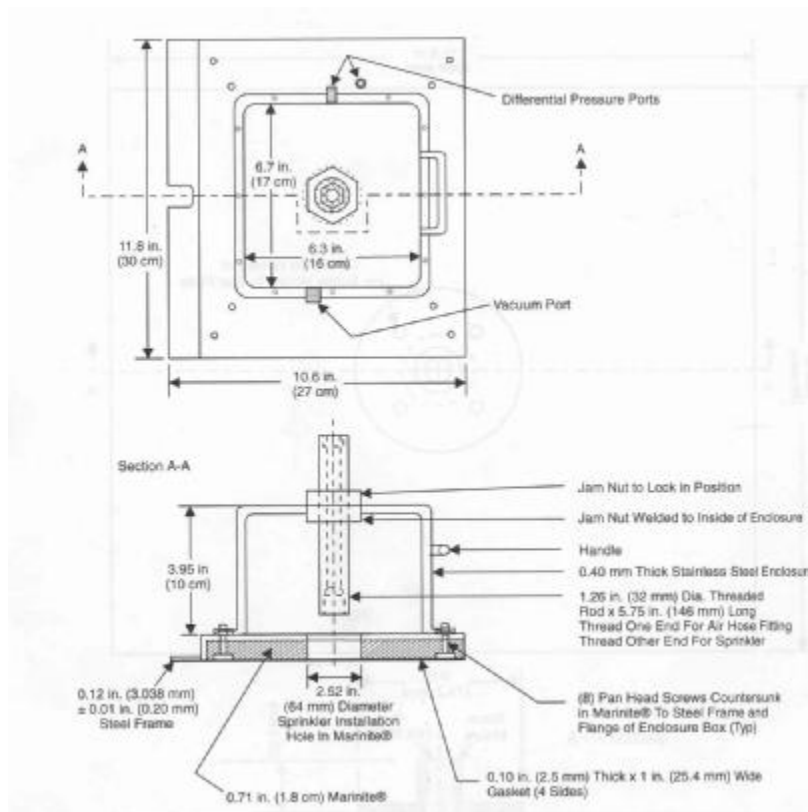


Figure 2 FMRC modified plunge tunnel test mounting plate

Four sprinklers were positioned centrally along the long axis of the room, two at 1.63 m and two at 6.18 m from the centre of the fire. One of each pair was a fully exposed pendent sprinkler.

During the fire tests, measurements were made of sprinkler operating times, gas velocities, temperatures and pressure 76 mm (and in some tests additionally 6 mm) beneath the ceiling near to the sprinkler heads, and temperature of water in the sprinkler pipe.

In two tests, the solid short wall was removed to investigate the effect of room size/room openings on the static pressure at the room centre, for a sprinklered and an unsprinklered case.

Phase 2 involved the development of a modified plunge test. Plunge test conditions were determined for recessed, flush and concealed sprinklers similar to those used in the Phase 1 fire tests which would represent a range of fire conditions and give thermal response results consistent with the Phase 1 fire tests.

In determining the appropriate plunge test conditions for recessed, flush and concealed sprinklers, the design of the mounting plate used for the FMRC standard sprinkler plunge tests was modified. Figure 1 is a schematic diagram of the FMRC standard plunge tunnel test mounting plate and Figure 2 is a schematic diagram of the FMRC modified plunge tunnel test mounting plate.

The modified plate was fabricated with a closed plenum to contain the portion of the sprinklers that would typically be mounted above the ceiling in normal installation. The initial comparison of fire test and plunge test results indicated that ceiling pressures generated by the fires needed to be simulated in the plunge test to achieve similar results. This was accomplished by partially evacuating the new mounting plate plenum and monitoring the pressure differential between the plenum and the plunge test tunnel.

Nine conditions (three gas velocities and three gas temperatures) were investigated in the plunge tests.

Plunge test requirements were developed for standard and quick response, recessed, flush and concealed sprinklers based on a comparison of the results of the plunge tests and the fire tests.

The conclusions of this work were:

- a) Flows through recessed and concealed sprinklers generated by pressure differentials associated with hot ceiling layers are important for the actuation of such sprinklers.
- b) Plunge tests conducted indicate that adverse pressure differentials can cause recessed and concealed sprinklers to fail to actuate.
- c) Response of glass bulb sprinklers is significantly delayed when the frame arms are in alignment with the ceiling gas flows generated by the fire.
- d) Plunge tests can be used to evaluate sensitivity of recessed, flush and concealed sprinklers by using a modified mounting plate with a plenum and by simulating fire induced pressures at the ceiling.

5 Thermal sensitivity

5.1 Thermal sensitivity tests for concealed and recessed residential sprinklers

The purpose of this stage of the project was to establish a suitable UK thermal sensitivity test for concealed and recessed residential sprinklers.

The thermal sensitivity test in British Standard Draft for Development DD 252: 'Components for residential sprinkler systems. Specification and test methods for residential sprinklers 2002'¹, is not suitable for evaluating concealed and recessed sprinklers. As a consequence of this, there is a recommendation appended with a note stating "For sprinklers which do not fit into the wind tunnel, equivalence of sensitivity is determined by a fire test (not yet standardised)".

In completing this stage of the project, USA and UK experiences were reviewed, a new thermal sensitivity test specified and developed and an experimental matrix of wind tunnel tests conducted. Tests to evaluate and investigate the effect of various parameters on the sprinkler thermal response were undertaken.

5.2 Review of USA and UK experience

Previous work on measuring the thermal sensitivity of concealed and recessed sprinklers has been conducted in the USA by Factory Mutual Research Corporation (FMRC)^{2,3} and Underwriters Laboratories (UL)⁴. A summary of this work is given, as follows.

5.2.1 Factory Mutual modified plunge test

FMRC use a heated wind tunnel plunge test procedure to evaluate the thermal sensitivity of recessed, flush and concealed sprinklers. This test procedure was the result of a research programme conducted by FMRC³. The research was carried out in two phases, Phase 1 and Phase 2.

Phase 1 involved full scale room fire tests. Sixteen fire tests were conducted to compare the response times of recessed, flush, and concealed sprinklers against fully exposed pendent sprinklers. 12 sprinkler models (4 recessed, 2 recessed sidewall, 1 flush, 3 concealed, 1 quick response pendent and 1 standard response pendent) from five manufacturers were tested. The sprinklers had different thermal elements (3 mm, 5 mm, 8 mm bulbs and fusible links) and 68°C or 74°C temperature ratings. The concealed sprinklers tested consisted of vented and unvented models.

The test room measured 3.66 m by 7.32 m by 2.44 m high and was constructed from wood studs and ½ inch gypsum board. The room had an open door at one end, 1.18 m wide by 2.06 m high, placed centrally along the short wall of the room.

The fire source was a nominal 130 kW, 0.46 m diameter, heptane pool fire for 15 tests and a nominal 260 kW, 0.6 m diameter heptane pool fire for one test. The fire was positioned centrally along and 1.02 m out from the short wall of the room, at the opposite end to the open door.

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The image features a dark blue background on the left side, which transitions into a white background on the right. The dark blue area is filled with a complex, abstract pattern of thin, light green lines that curve and overlap, creating a sense of depth and movement. The 'bre' logo is positioned in the upper left of this dark blue area. On the right side, the title and other report details are printed in a clean, black, sans-serif font. The overall design is modern and professional.

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**DCLG Final Research
Report**

**Effectiveness of sprinklers in
residential premises – an
evaluation of concealed and
recessed pattern sprinkler
products**

Section 5: Thermal sensitivity

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