Smoke and Heat Detector Performance: Field Demonstration Test Results

Distributed compliments of

Simplex

Smoke and Heat Detector Performance: Field Demonstration Test Results

J. A. DROUIN
and
ARTHUR E. COTE, P.E.

Fire service, hotel, and fire protection industry representatives witnessed a series of 11 demonstration test fires conducted September 8-10, 1982 in an old hotel scheduled for demolition in Ft. Lauderdale, Florida. The purpose of the fire tests was to observe the operation of a retrofit automatic sprinkler system installed with quick-response sprinklers and polybutylene pipe and to also observe the performance of smoke and heat detectors installed in various locations in the five test rooms.

A previous article described sprinkler performance. This article will discuss the performance of smoke and heat detectors during those 11 tests.

The fire tests were designed to simulate common hotel fire scenarios. The following scenarios were chosen for the test series:

- Series A: Arson (flammable liquid) fire in a hotel guest room;
- Series B: Flaming-started fire in a wastepaper basket in a hotel guest room;
- Series C: Arson fire involving luggage in a hotel guest room;
- Series D: Hotel corridor fire tests (maid’s cart and arson);
- Series E: Fire in maid’s cart in a hotel storage room;
- Series F: Smouldering started fire in a hotel guest room.

The fire tests were conducted in five rooms on the second floor of a vacant five-story, fire-resistive hotel. Weather conditions during the test series included temperatures ranging from 84–87°F and relative humidity between 75–80 percent. The hotel was not air-conditioned at the time of the test series.

Ceiling heights in the guest rooms and corridor were 8 feet, 5 inches and ceiling height in the storage room was 9 feet, 2 inches. Walls and ceiling were noncombustible plaster on concrete.

Table 1 provides additional information on test numbers, room numbers, dimensions, room use, fire scenarios, fire test methods, furnishings, and ventilation conditions.

Nine of the eleven fires were flaming-started and two were smouldering-started. In the smouldering fires, neither test fire progressed from the smouldering stage to the flaming stage. Test 9 was terminated after two hours with no visible smoke and no detectors operated.

Detector System Design

Each test room was equipped with a series of detector clusters consisting of a 135°F rate-of-rise/fixed-temperature heat detector, a photoelectric smoke detector, and an ionization smoke detector in each cluster. A typical cluster is shown in Figure 1.

A total of 42 detectors in 14 clusters was installed as shown in Figure 2. The smoke detectors used in these tests were “off-the-shelf,” selected at random, and not prescreened to be extra sensitive. The average sensitiv-
<table>
<thead>
<tr>
<th>Test</th>
<th>Test</th>
<th>Room</th>
<th>Dimen-</th>
<th>Area</th>
<th>Furnishings</th>
<th>Test Scenario</th>
<th>Fire Start</th>
<th>Ventilation</th>
<th>Detector Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1, 5</td>
<td>1</td>
<td>17'6&quot; x 13'10&quot; 8'5&quot; ceiling height</td>
<td>Guest room</td>
<td>Shag wall-to-wall carpeting; drapes; 2 vinyl-covered chairs; end table; lamp; double bed with box spring, polyurethane foam mattress (with cotton fabric covering); two sheets, and two foam rubber pillows with pillow cases.</td>
<td>Arson</td>
<td>Test 1: ¾ gallon mineral spirits poured on edge of bed and on floor to the drapes.</td>
<td>Doors &amp; windows closed in both tests.</td>
<td>• Ceiling — center of room • Ceiling — entryway • Wall — 6&quot; below ceiling</td>
</tr>
<tr>
<td>B</td>
<td>3, 7</td>
<td>3</td>
<td>17'7&quot; x 13'10&quot; 8'5&quot; ceiling height</td>
<td>Guest room</td>
<td>Same as Room 1, with vinyl wallpaper attached to wall behind draperies. Draperies in Test 3 were fiberglass with cloth sheen behind; draperies in Test 7 were 60% rayon, 32% acetate, and 8% polyester.</td>
<td>Flaming waste-basket</td>
<td>Cigarette lighter placed through hole at bottom of plastic wastepaper basket, igniting rolled and crumpled newspaper.</td>
<td>Doors &amp; windows closed in Test 3.</td>
<td>• Ceiling — center of room • Ceiling — entryway • Wall — 6&quot; below ceiling • Wall — ½&quot; below ceiling</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>3</td>
<td>17'7&quot; x 13'10&quot; 8'5&quot; ceiling height</td>
<td>Guest room</td>
<td>Same as above, but without chairs, lamp, end table.</td>
<td>Luggage and clothing identical to that in Room 1, Test 10, were added</td>
<td>Arson (luggage)</td>
<td>Same as Room 1, Test 10, but with an additional ½ gallon of acetone spread over clothing and suitcase.</td>
<td>Door to guest room open, windows closed in Test 11.</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>1</td>
<td>17'6&quot; x 13'10&quot; 8'5&quot; ceiling height</td>
<td>Guest room</td>
<td>Same as Tests 1 and 3, but without chairs, lamp, end table.</td>
<td>Approx. 10 lbs. of clothing (generally 65% polyester and 35% cotton) were dumped on bed. A suitcase was placed on top of clothing.</td>
<td>Arson (luggage)</td>
<td>Test 10: 4 oz. of acetone-based fingernail polish remover was spread on clothing and suitcase. A cigarette lighter provided ignition.</td>
<td>Doors and windows closed in Test 10.</td>
</tr>
<tr>
<td>D</td>
<td>4, 8</td>
<td>5</td>
<td>3'10&quot; x 37'8&quot; 8'5&quot; ceiling height</td>
<td>Corridor</td>
<td>Shag wall-to-wall carpeting</td>
<td>Arson</td>
<td>Test 4: 1 gallon of flammable liquid (75% acetone and 25% mineral spirit) poured on carpet. Flaming newspaper provided ignition.</td>
<td>Doors &amp; windows closed in both tests.</td>
<td>• Ceiling — left • Ceiling — center • Ceiling — right</td>
</tr>
</tbody>
</table>

(Table continued on next page)

FIRE JOURNAL — JANUARY 1984 • 35
### Table 1 (continued)

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Test Nos.</th>
<th>Room No.</th>
<th>Dimensions</th>
<th>Area</th>
<th>Furnishings</th>
<th>Test Scenario</th>
<th>Fire Start</th>
<th>Ventilation</th>
<th>Detector Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>6</td>
<td>4</td>
<td>5'8½&quot; x 14&quot;</td>
<td>Storage room</td>
<td>Typical hotel maid's cart, with plastic trash bag filled with newspaper, cloth, and plastic shower curtain. Linen towels were on top of the cart.</td>
<td>Maid's cart fire (flaming ignition)</td>
<td>Cigarette lighter placed through hole at bottom of trash bag, igniting newspaper.</td>
<td>Doors &amp; windows closed.</td>
<td>Ceiling — center of room</td>
</tr>
<tr>
<td>F</td>
<td>2, 9</td>
<td></td>
<td>14'5½&quot; x 12'2&quot;</td>
<td>Guest room</td>
<td>Same as Room 1, but without chairs, lamp, end table.</td>
<td>Smouldering</td>
<td>Test 2: energized 1,000-watt iron placed on bed near pillow. Test 9: energized 1,500 watt iron placed on bed near pillow.</td>
<td>Doors &amp; windows closed in both tests. In Test 9, windows in Room 3 were open.</td>
<td>Ceiling — center of room Ceiling — entryway Wall — 6&quot; below ceiling</td>
</tr>
</tbody>
</table>

### Figure 2.

![Diagram of Test Sites and Rooms](image-url)

**Legend**
- □ Photoelectric Smoke Detectors
- ○ Ionization Smoke Detectors
- ◯ Heat Detectors

36 • FIRE JOURNAL — JANUARY 1984
ity for the ionization detectors was 1.30 percent per foot; the average sensitivity for the photoelectric detectors was 1.75 percent per foot. For the test series, individual detectors were identified by number and by whether they were ionization or photoelectric. Detector activation times were recorded on a Simplex 2120 Multiplex System.

Smoke Obscuration Measurements

Visible smoke measurements were made using a horizontal light/photocell arrangement (1-meter light path) in each of the five test rooms. The photocell/light was placed in approximately the center of each room, roughly 60 inches above the floor. The outputs of the photocells were collected and stored by a Wang computer system.

Test Results

Table 2 presents time-to-response for the first ionization detector, the first photoelectric detector, the first heat detector, and the first sprinkler head for 10 of the 11 tests. Test 9 was terminated and data collection did not occur.

Table 2 also presents temperature measurements at the ceiling and five-foot level and smoke obscuration measurements at the 5'-0 level at the times of first detec-

<table>
<thead>
<tr>
<th>Test Results</th>
<th>Table 2.</th>
<th>Test</th>
<th>Room</th>
<th>First</th>
<th>First</th>
<th>First</th>
<th>First</th>
<th>Difference</th>
<th>Second</th>
<th>Second</th>
<th>Type</th>
<th>Difference</th>
<th>Temperature (°F)</th>
<th>Smoke 5'-0 Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series No.</td>
<td>Room No.</td>
<td>Time</td>
<td>Location</td>
<td>Time</td>
<td>Location</td>
<td>Time</td>
<td>Location</td>
<td>Time</td>
<td>Location</td>
<td>Type</td>
<td>Detector</td>
<td>Type</td>
<td>Detector</td>
<td>Time</td>
</tr>
<tr>
<td>A 1 1</td>
<td>1 0.07</td>
<td>0.11</td>
<td>ceiling</td>
<td>0.21</td>
<td>ceiling</td>
<td>0.38</td>
<td>I</td>
<td>0.04</td>
<td>0.31</td>
<td>0.10</td>
<td>118.8</td>
<td>89.6</td>
<td>100</td>
<td>2 70.1</td>
</tr>
<tr>
<td>A 5 1</td>
<td>0.06</td>
<td>0.11</td>
<td>entry</td>
<td>0.06</td>
<td>I/H</td>
<td>0.00</td>
<td>0.05</td>
<td>0.10</td>
<td>105.9</td>
<td>73</td>
<td>9.1</td>
<td>26 33.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 3 3</td>
<td>0.31</td>
<td>0.34</td>
<td>wall</td>
<td>1.57</td>
<td>6.01</td>
<td>I</td>
<td>0.03</td>
<td>1.00</td>
<td>97.3</td>
<td>60</td>
<td>100</td>
<td>26 26.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 7 3</td>
<td>1.01</td>
<td>1.10</td>
<td>wall</td>
<td>1.18</td>
<td>1.35</td>
<td>I</td>
<td>0.09</td>
<td>1.34</td>
<td>87.6</td>
<td>78.7</td>
<td>100</td>
<td>48 20.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 11 3</td>
<td>0.12</td>
<td>0.28</td>
<td>entry</td>
<td>0.07</td>
<td>N/S</td>
<td>0.05</td>
<td>0.30</td>
<td>88.1</td>
<td>89.2</td>
<td>100</td>
<td>21 37.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 10 1</td>
<td>0.12</td>
<td>0.38</td>
<td>entry</td>
<td>1.09</td>
<td>1.09</td>
<td>I</td>
<td>0.26</td>
<td>0.57</td>
<td>98.6</td>
<td>105.7</td>
<td>100</td>
<td>92 2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 4 5</td>
<td>0.09</td>
<td>0.23</td>
<td>corridor</td>
<td>0.19</td>
<td>0.17</td>
<td>I</td>
<td>0.10</td>
<td>0.08</td>
<td>120.7</td>
<td>109.0</td>
<td>100</td>
<td>20 6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 8 5</td>
<td>0.24</td>
<td>0.57</td>
<td>N/A</td>
<td>1.53</td>
<td>I</td>
<td>0.33</td>
<td>1.29</td>
<td>0.50</td>
<td>99.8</td>
<td>90.5</td>
<td>100</td>
<td>80 6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E 6 4</td>
<td>0.33</td>
<td>0.42</td>
<td>ceiling</td>
<td>2.12</td>
<td>2.12</td>
<td>I</td>
<td>0.09</td>
<td>1.39</td>
<td>90.3</td>
<td>91.1</td>
<td>97</td>
<td>16 42.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 2 2</td>
<td>1:44:41</td>
<td>0:36:12</td>
<td>entry</td>
<td>N/A</td>
<td>N/S</td>
<td>P</td>
<td>1:06:29</td>
<td>N/S</td>
<td>36:00</td>
<td>91.0</td>
<td>91.9</td>
<td>94</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>F 3 2 3</td>
<td>0:30:12</td>
<td>0:03:12</td>
<td>entry</td>
<td>N/A</td>
<td>N/S</td>
<td>P</td>
<td>1:06:29</td>
<td>N/S</td>
<td>36:00</td>
<td>91.0</td>
<td>91.9</td>
<td>94</td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>
Detector Response

The ionization detector operated first in seven flaming-started tests, the heat detector operated first in one flaming-started test (Test 11), and both the heat detector and ionization detector operated first simultaneously in one flaming-started test (Test 5).

The photoelectric detector operated first in the one completed smouldering test (Test 2).

Detector Performance Compared to Sprinkler Performance

There were eight flaming-started tests in which sprinklers were provided.

The ionization smoke detector operated at the same time as the fast-response sprinkler in one test (Test 5) and before the fast-response sprinkler in all other flaming-started tests (Tests 1, 3, 4, 6, 7, 8, and 10).

The photoelectric detector operated before the fast-response sprinkler in six of the eight flaming-started tests. The two fires in which the sprinklers operated before the photoelectric detector were Test 5 (started with 1/4 gallon of gasoline) and Test 4 (started with one gallon of liquid fuel consisting of 75 percent acetone and 25 percent mineral spirit).

The heat detector operated at the same time as the fast-response sprinkler in three tests (Tests 10, 5, and 6) and before the fast-response sprinkler in three flaming-started tests (Tests 1, 3, and 7). Sprinklers operated before the heat detectors in two tests (Tests 4 and 8).

In the eight flaming-started fires in which sprinklers were provided, the first detector to respond activated an average of approximately 3 minutes (minimum of 0 seconds, maximum of 13 minutes, 34 seconds) before the sprinkler.

In all the fire tests, at the time that the first smoke detector operated, the smoke obscuration at the five-foot level was very low (94 to 100 percent transmission).

Smoke levels in the test rooms prior to sprinkler activation varied from light smoke (100 percent transmission) to heavy smoke (16 percent transmission/42.8 obscuration per foot or greater), depending upon the type of fuels used to initiate the fire. After sprinkler activation, there was an increase in the amount of visible smoke.

In the smouldering-started fire test (Test 2), the sprinkler and heat detector did not operate.

 Ionization Detector Performance Compared to Photoelectric Detector Performance

The ionization detector operated before the photoelectric detector in all flaming fires. Ionization detectors responded an average of 13.2 seconds faster than photoelectric detectors in these flaming-started fire tests (minimum 3 seconds, maximum 33 seconds). The photoelectric detector operated well in advance of the ionization detector in the one completed smouldering fire (Test 2).

In this test, the room photoelectric detector operated 1 hour, 8 minutes, 29 seconds before the room ionization detector. The photoelectric detector located in the corridor operated 33 minutes, 22 seconds before the ionization detector in the room.

Smoke Detector (Ionization and Photoelectric) Compared to Heat Detector Performance

The smoke detector operated before the heat detector in seven of the flaming-started tests, the heat detector operated before the smoke detector in one flaming-started test (Test 11), and the heat detector operated at the same time as the smoke detector in one test (Test 5).

In the seven flaming-started tests in which the smoke detector operated before the heat detector, the average difference in activation time was approximately 2½ minutes (minimum 10 seconds, maximum 10 minutes, 57 seconds).

In the one flaming-started test in which the heat detector operated before the smoke detector, the difference in activation time was five seconds.

Conclusions

- The location of the detectors within each room did not appear to be a significant factor in detector activation times.
- The ionization smoke detectors operated first in the majority of the flaming-started fires.
- The photoelectric smoke detectors operated an average of 13.2 seconds after the ionization detectors in the flaming-started fires.
- The smoke detectors operated before the heat detectors in the majority of the flaming-started fires.
- The smoke detectors operated an average of 2½ minutes faster than the heat detectors in the flaming-started fires.
- The photoelectric smoke detector operated first in the smouldering-started fires.
- The photoelectric smoke detector operated 1 hour, 8 minutes, 29 seconds before the first ionization detector in the smouldering-started fire. In this test, all photoelectric detectors in the room, as well as photoelectric detectors in the corridor beyond the closed door, responded before the first ionization detector.
- Detectors operated an average of three minutes faster than quick-response sprinklers in the flaming-started fires. The sprinkler and heat detector did not operate in the smouldering-started fire.
- At the time the first detector operated, the smoke obscuration at the five-foot level was very low.
- In seven of the eight tests in which sprinklers operated, the detectors provided an additional advance warning, prior to sprinkler operation of between 8 seconds and 13½ minutes. In one test, the sprinkler and first detector operated simultaneously.