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The Response Time of Different Sprinkler Glass Bulbs in a Residential Room Fire Scenario

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Abstract. The response time of fire sprinklers is essential for their performance, especially in applications where life safety protection is desired. The earlier the sprinkler activates, the smaller the size of the fire. Most commercial residential sprinklers are fitted with 3 mm, 68°C glass bulbs. However, thinner sprinkler glass bulbs with lower operating temperatures are available. The aim of this study was to determine the response time—and the corresponding heat release rate—of different glass bulbs in a residential room fire scenario. A series of tests were conducted inside a compartment measuring 3.66 m by 3.66 m having a ceiling height of 2.5 m. The compartment was either enclosed or had two walls removed to provide a more ventilated scenario. A propane gas burner was positioned at one of the corners. The mass flow rate of the gas was controlled such that either 'slow', 'medium' or 'fast' fire growth rate scenarios were simulated. In each test, nine Response Time Index (RTI) and operating temperature combinations were tested. Each test was replicated three times. In addition, two commercial fire detectors were tested. The results show that the fire is considerably smaller upon activation with a combination of a low RTI and a low operating temperature, as compared to the 3 mm, 68°C glass bulb typically used for residential sprinklers. The operating temperature proved to have a larger impact on the results than the RTI. The heat from the fire was typically detected by the fire detectors prior to the activation of the sprinkler glass bulbs, especially for the 'slow' and 'medium' fire growth rate scenarios.

Keywords: Sprinkler glass bulbs, Response Time Index (RTI), Operating temperature, Fire detectors, Response time, Residential room fire scenario

1. Introduction

Although the life safety benefits of residential sprinklers in general terms are well-documented by for example Hall [1] and Hall et al. [2], there are fire scenarios where sprinkler activation may occur too late to save the occupants of a room. A review of British fire statistics by BRE Global [3] indicated that most fatalities in care homes arise from occupants accidentally setting fire to bedclothes, night-clothes etc. whilst in bed. There was no available information to determine whether the severity of such a fire at the time the sprinkler operates would be fatal or

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whether there would be a probability for survival. An experimental program [3] by BRE Global demonstrated that a residential sprinkler in a bedroom will not operate fast enough to prevent death, or very severe injury, to the occupant of a bed where the nightwear or bed coverings of the bed have ignited. However, other occupants of the room are likely to have survived. For one of the tests, the sprinkler at the celling was manually activated upon fire detection of a smoke detector. Both the bed occupant and any other occupants of the room were judged to have survived, with only minor injuries.

Fleming [4] conducted in 1985 a literature survey and analysis of fast response sprinkler technology. This was later updated and republished with the 1991 edition of the NFPA Automatic Sprinkler Systems Handbook [5] and contains a chronology of the development of fast response sprinkler technology, up until mid-1991. One of the key events of the chronology is the introduction by Factory Mutual Research of the concept of the Response Time Index (RTI) in the late 1970s [6, 7]. This measure improved the terminology of sprinkler sensitivity and can be used as a basic property of a sprinkler.

The first edition of ISO 6182–1 [8] from 1993 stipulates that "Fast response" sprinklers shall have a thermal element with an RTI of 50 $(ms)^{1/2}$ or less and "Standard response" sprinklers an RTI of between 80 $(ms)^{1/2}$ and 350 $(ms)^{1/2}$, when the sprinkler is tested in the orientation resulting in the fastest operating time. Sprinklers having an RTI of between 50 $(ms)^{1/2}$ 80 $(ms)^{1/2}$ are denoted "Special response" sprinklers. The equipment used to conduct this measurement is commonly referred to as a "plunge oven" as the tested sprinkler is plunged into a hot stream of air where the activation time is recorded. The specific RTI of a sprinkler is typically not published by the sprinkler manufacturer; however, fast response thermal elements are widely used for both residential as well as for non-storage and storage area sprinklers. Most commercial residential sprinklers are fitted with 3 mm glass bulbs having a nominal operating temperature of 68°C or a high-sensitivity solder link, usually with a nominal temperature rating of 74°C. Sprinklers with these thermal elements fall within the "Fast response" classification category. The fast response characteristic and a unique water distribution pattern are essential for the performance of residential sprinklers.

2. Objective

The aim of this study was to determine the response time—and the corresponding heat release rate—of different sprinkler glass bulbs in a residential room fire scenario. The earlier the sprinkler activates, the smaller the size of the fire, however, experimental data giving an indication on the actual fire size upon sprinkler activation is missing. The experimental data provided in the study could also be used for the validation of computational fluid dynamics (CFD) modeling of sprinkler activation.

Very thin sprinkler glass bulbs with lower operating temperatures than 68°C are readily available from several sprinkler glass bulb manufacturers, but are seldom or never used for residential sprinklers. These glass bulbs are, however, commonly

used for automatic water mist fire protection nozzles. Three different fire scenarios were simulated with a propane gas sand bed burner. The fire scenarios had either a 'slow', 'medium' or 'fast' fire growth rate in accordance with the exponential t-squared (t^2) fire growth rate curves commonly used for fire protection design purposes, refer to Eq. (1).

$$\dot{Q} = \alpha t^2 \tag{1}$$

where $\dot{Q}$ is the heat release rate (kW), α is the fire growth coefficient (kW/s^2) and t is time (s).

Based on the knowledge of the fire growth rate, the corresponding heat release rate (HRR) at the response times of the glass bulbs was calculated. In addition, the fire detection time of two commercial multi-criteria detectors was determined. Combined heat and smoke detectors may be a viable option for the detection of fire if they are considerably faster than sprinkler glass bulbs, allowing the activation of deluge sprinklers or water mist nozzles within a room.

Although earlier activation of a residential sprinkler would be beneficial from the aspect of improving the probability for survival or reducing fire damages, the operating sensitivity must always be balanced against the probability of unintended water discharge and the potential for operating excessive numbers of sprinklers. Therefore, it should be regarded that the use of lower sprinkler temperature ratings would be limited by climate conditions, conditions of the actual building and the activities in the building during construction and use. Thinner glass bulbs would also reduce the mechanical strength of the bulb and could require more stringent routines during installation and related to the inspection, control and maintenance of the sprinkler system. The practical implications of the temperature rating and operating sensitivity are discussed in the paper.

3. Experimental Set-Up

The tests were conducted inside a compartment having a 3.66 m by 3.66 m (13.4 m^2) floor area i.e. 12 ft. by 12 ft., which is identical with the minimum listed coverage area of commercial residential sprinklers and a ceiling height of 2.5 m. The compartment was built from non-combustible wall boards with a nominal thickness of 12 mm, on a framework of wood studs. The compartment was either enclosed or had two walls removed to provide a fully ventilated scenario, mimicking a larger room. The enclosed compartment was fitted with a door opening; however, the opening was sealed closed during the tests. The compartments are shown in Fig. 1.

A propane gas sand bed burner was positioned at one of the corners of the compartment. The burner was sized 305 mm by 305 mm (0.09 m^2) and was positioned 50 mm from each of the walls, respectively. The burner is similar to the burner used in ISO 9705:1993 [9].
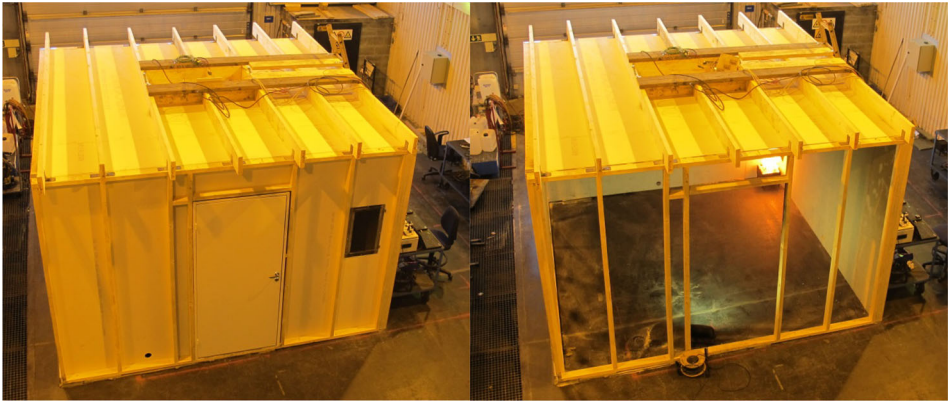
Figure 1. The test compartment was either enclosed (left hand side photo) or had two walls removed to provide a fully ventilated fire scenario.

4. The Glass Bulb Mounts and Sprinkler Glass Bulbs

A mount was designed to replicate the design of a pendent, non-recessed automatic sprinkler, except that the mount allowed the installation of three sprinkler glass bulbs. The vertical distance from the ceiling to the mid-point of glass bulbs was approximately 20 mm and the horizontal distance between each of the bulbs in the mount was 23 mm. The mount is shown in Fig. 2. The glass bulbs were under force by a compression spring, in order to simulate the pressure from water on an actual sprinkler glass bulb. The force acting on a bulb from the compression spring was similar to a water pressure of approximately 1 bar. Authentic sprinkler compression screws and disc springs were used to secure the bulbs such that they were exposed to the heat in a similar fashion of an actual sprinkler. The torque applied on the compression screw was in accordance with instructions from the sprinkler manufacturer that provided the item. The operation of the individual glass bulbs was determined by an electrical micro switch that closed an electrical circuit upon activation. The activation time was measured with an accuracy of 10 ms.

In each test, nine different Response Time Index (RTI) and glass bulb nominal operating temperature combinations were tested, by the installation of three mounts as listed in Table 1. The characteristics of the individual glass bulbs were provided by the manufacturer of the bulbs and were not confirmed by any additional testing. By using a specific fluid, some of the glass bulbs with an actual diameter of 3 mm had response characteristics similar to 2.5 mm glass bulbs, as noted in the table.

The mounts were installed side-by-side at the center point of the compartment, with the centermost glass bulb on each mount, respectively, on a radius of 2.6 m from the compartment corner with the propane gas sand bed burner. The horizontal distance between the mounts was 72 mm. The mounts were positioned on a
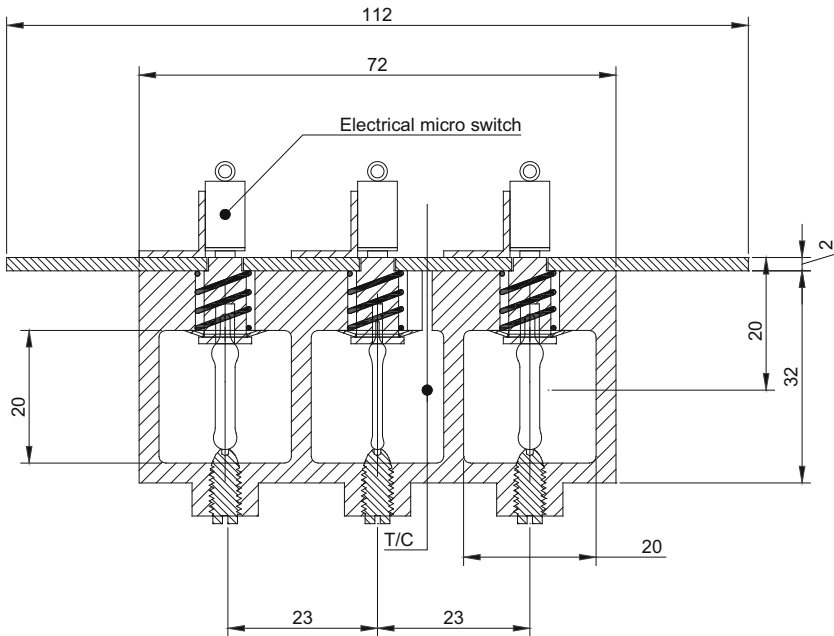
Figure 2.   The principle design of the mount for the sprinkler glass bulbs. Each glass bulb was pressurized by a compression spring and a piston was connected to an electrical micro switch for the recording of the activation time. A thermocouple (T/C) was positioned at the mid-point of the centermost glass bulb.

Table 1
The Nine Different Response Time Index (RTI) and Nominal Glass Bulb Operating Temperature Combinations that were Tested

No.	Type of bulb	RTI[a] $[(ms)^{1/2}]$	Bulb diameter (mm)	Bulb length (mm)	Nominal operating temperature (°C)	Color code
1	F3	32	3	16	68	Red
2	F3	32	3	16	57	Orange
3	F3	32	3	16	47	Transparent
4	F3-F	24	3[b]	16	68	Red
5	F3-F	24	3[b]	16	57	Orange
6	F3-F	24	3[b]	16	47	Transparent
7	F1.5	14	1.5	16	68	Red
8	F1.5	14	1.5	16	57	Orange
9	F1.5	14	1.5	16	47	Transparent

[a] Provided by the manufacturer and calculated using a C-factor of 0.5
[b] By using a specific fluid, the RTI of the glass bulb was similar to a 2.5 mm glass bulb

300 mm by 300 mm plate that was removed from the ceiling when exchanging the glass bulbs.

5. The Multi-criteria Fire Detectors

In addition to the three sprinkler glass bulb mounts, two commercial multi-criteria fire detectors were installed at the 2.6 m radius from the compartment corner with the propane gas sand bed burner. Each detector had two heat sensors (for the purpose of redundancy), positioned opposite each other, on its cylindrical body. The vertical distance from the ceiling to the heat sensors of the detector was approximately 40 mm. The individual detector units were orientated 90° relative to each other in order to represent any orientation in practice. The temperature of the heat sensors of the individual detectors was measured every other second. For these tests, fire detection was based on a fixed-temperature threshold of 40°C, no other criterion was used. However, in a practical application, the operation of a sprinkler system by a separate fire detection system would require both that smoke is detected and that the fixed-temperature limit is reached. The fire detection time was defined as the average fire detection time of both detectors. Figure 3 depictures the three sprinkler glass bulb mounts and the two detectors when installed at the ceiling of the test compartment.

6. Measurements and Instrumentation

Besides the measurement of the response times of the individual sprinkler glass bulbs and the fire detection times of the fire detectors, the following parameters were measured:

The gas temperature, at the position of the centermost glass bulb on each mount, respectively.

- The gas temperature directly above the sand bed burner. The intent was to confirm fire ignition of the burner.
- The mass flow rate of gas to the propane gas burner. Based on this measure the heat release rate was calculated.
- The gas temperature measurements were made using sheathed, Type K thermocouples having a diameter 0.5 mm. Measurements were conducted once every second.

7. Test Procedures

The mass flow rate of the propane gas burner was controlled to provide either a 'slow', 'medium' or 'fast' fire growth rate scenario. The control unit consists of an electronic flow meter connected to a Programmable Logic Controller (PLC) able to control the mass flow of gas according to any pre-determined curve up to a heat release rate of 300 kW. The maximum error margin for the entire effect
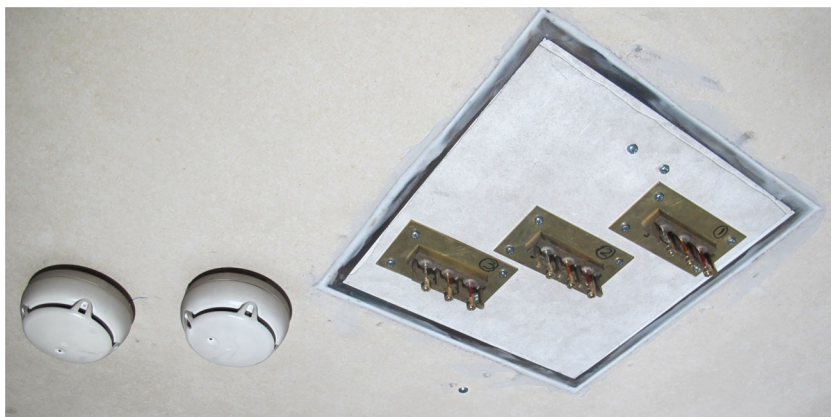
Figure 3. The three sprinkler glass bulb mounts and the two fire detectors when installed at the ceiling of the test compartment. Each device was positioned with its centerpoint on a 2.6 m radius from the corner with the propane gas burner.

range is under $\pm$ 2%. A small pilot igniter was positioned above the burner. However, the fire did not ignite until the gas had filled the pipe to the burner and had overcome the flow resistance of the sand bed. Prior this, the mass flow of gas was too low to allow the establishment of an open flame. The flow of gas was manually terminated as soon as all glass bulbs had activated. Each fire scenario was replicated three times in order to account for any test-to-test variability.
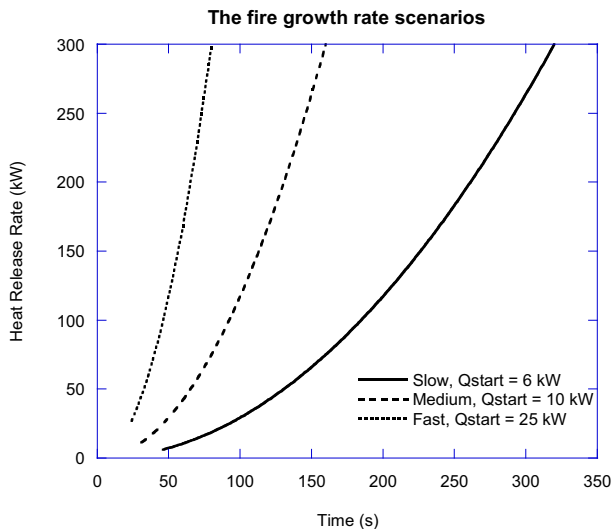
Table 2 shows the initial heat release rate at fire ignition, the corresponding time and the remaining time to reach 300 kW, for each of the fire growth rate scenarios, respectively.

Figure 4 shows the heat release rates, respectively, as a function of time for each of the three fire growth rates.

The response times of the sprinkler glass bulbs and the fire detection times of the fire detectors were determined from the initiation of the gas, e.g. time zero in Fig. 4 and not from actual fire ignition. The fact that a flaming fire did not occur from the very start of the test may have a certain influence on the activation times of the glass bulbs in that the time otherwise would have been slightly shorter.

Table 2
The Initial Heat Release Rate at Fire Ignition, the Corresponding Time and the Remaining Time to Reach 300 kW, for Each of the Fire Growth Rate Scenarios, Respectively

Fire growth rate scenario (time constant)	Initial heat release rate (kW) at fire ignition	Corresponding (approximate) time (s)	Remaining time to reach 300 kW (s)
Slow (α = 0.00293)	6	45	320 − 45 = 275
Medium (α = 0.01172)	10	30	160 − 30 = 130
Fast (α = 0.0469)	25	23	80 − 23 = 57

The fire growth rate scenarios

Figure 4. The 'slow', 'medium' and 'fast' fire growth rate scenarios of the tests.

However, the amount of energy represented under the initial (non-fire) part of the fire growth rate curves is small compared to the remaining part of the curves.

8. Test Results

The mean heat release rate at the activation of each of the sprinkler glass bulbs for each of the fire growth rates and compartment conditions, respectively, is shown in Figs. 5, 6 and 7. The bars represent one standard error of the mean and indicate the variation in test results.

Figures 8 and 9, respectively, shows the gas temperature as measured at the position of the centermost glass bulb on each mount, for all three fire growth rates. The data represents the mean of the three measurement points, one measurement point on each glass bulb mounts, respectively.

Figure 10 shows the mean heat release rate at fire detection of the fire detectors for all fire scenarios and compartment conditions.

9. Discussion

In addition to the characteristics of the thermal element of a sprinkler and its coverage area, it should be recognized that the response time is influenced by several other parameters, for a given fire scenario. These parameters include the degree of exposure of the thermal element to the hot gases of the ceiling jet (e.g. whether the sprinkler is semi-recessed, flush or flat-concealed), the size and ceiling height of the room, the ceiling construction and ceiling slope. Although the results are
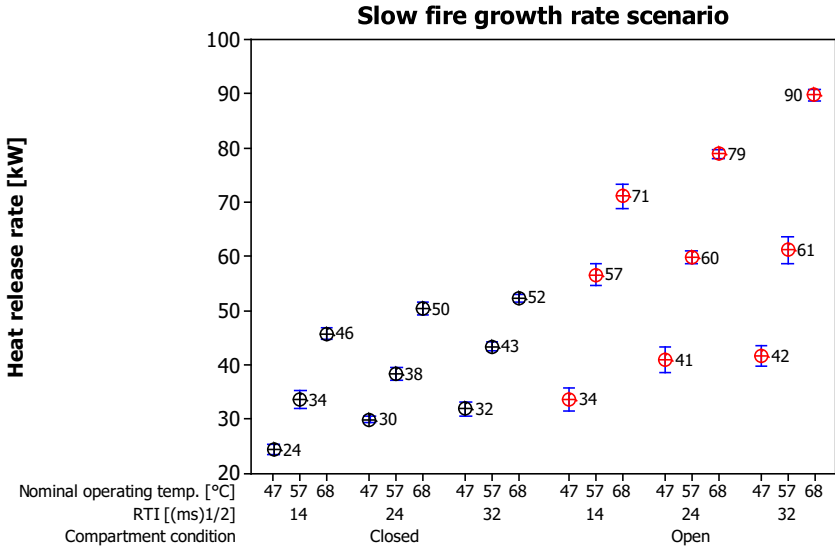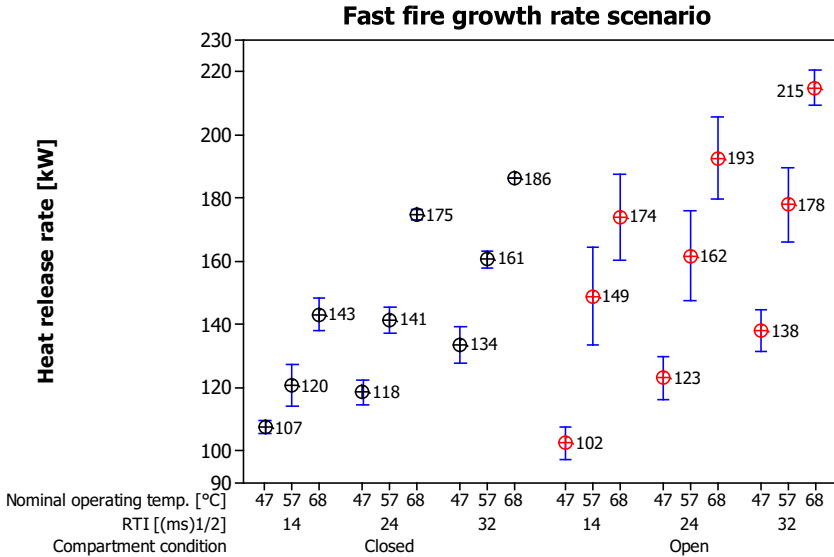
Figure 5. The mean heat release rates at the activation of the sprinkler glass bulbs for the 'slow' fire growth rate scenario under both compartment conditions.
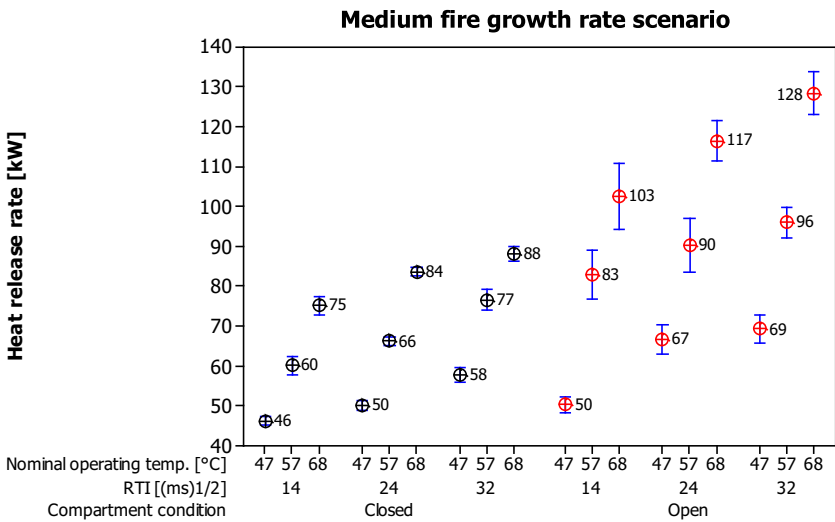
Figure 6. The mean heat release rates at the activation of the sprinkler glass bulbs for the 'medium' fire growth rate scenario under both compartment conditions.

only directly applicable to the test conditions used, they capture trends related to the parameters that were varied.

Figure 7. The mean heat release rates at the activation of the sprinkler glass bulbs for the 'fast' fire growth rate scenario under both compartment conditions.

As expected, the sprinkler glass bulb having the lowest RTI and the lowest nominal operating temperature activated the earliest (smallest fire size) and the sprinkler bulb with the highest RTI and the highest nominal operating temperature last (largest fire size).

Whether the compartment was fully enclosed or open, e.g. two walls removed, had a large influence on the time to activation and the corresponding heat release rate, especially in the 'slow' and 'medium' fire growth rate scenarios. For the sprinkler glass bulbs with the lowest operating temperature, this effect is not as pronounced. With few exceptions, the sprinkler glass bulbs having the same temperature rating and RTI activated earlier (smaller fire size) inside the closed compartment as compared to the open compartment. Intuitively, this seems valid as the combustion gases built a layer of hot gases inside the closed compartment. This is verified by the fact that the measured temperatures at the sprinkler glass bulbs rise faster inside the closed compartment. The measurement data also indicate larger temperature fluctuations for the open scenario, as compared to the closed compartment. Correspondingly, it was observed that the activation times of the individual glass bulbs varied more in the open scenario, especially for the 'medium' and 'fast' fire growth rate scenarios.

Another observation is that the nominal operating temperatures of the glass bulbs have a stronger effect on the results than does the RTI. This is true for all three fire growth rate scenarios. In other words, a reduction of the nominal operating temperature of a sprinkler glass bulb has a larger effect on the speed of response than a reduction of its thermal sensitivity, at least within the relatively

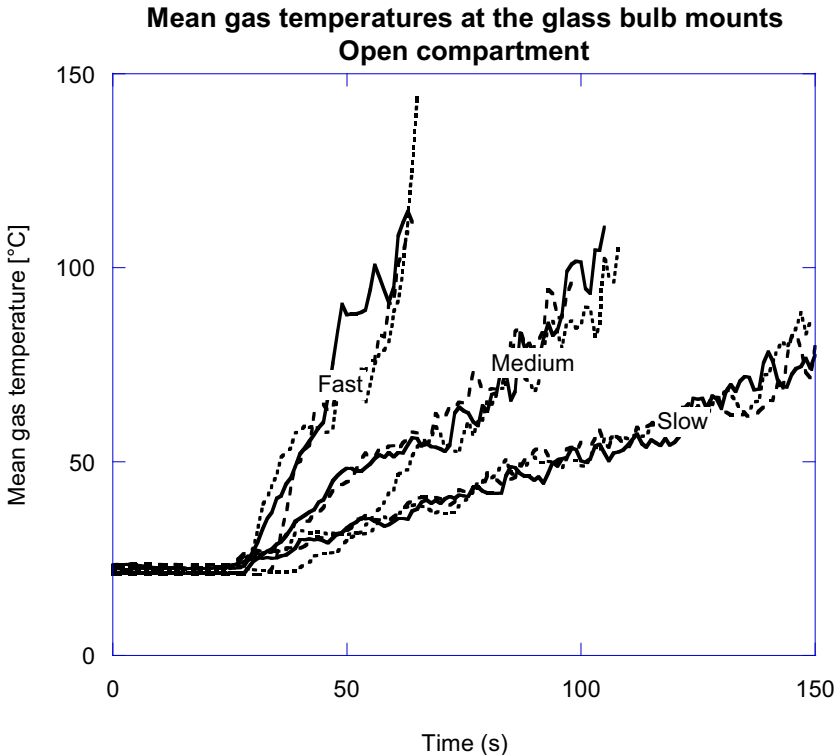**Mean gas temperatures at the glass bulb mounts Closed compartment**
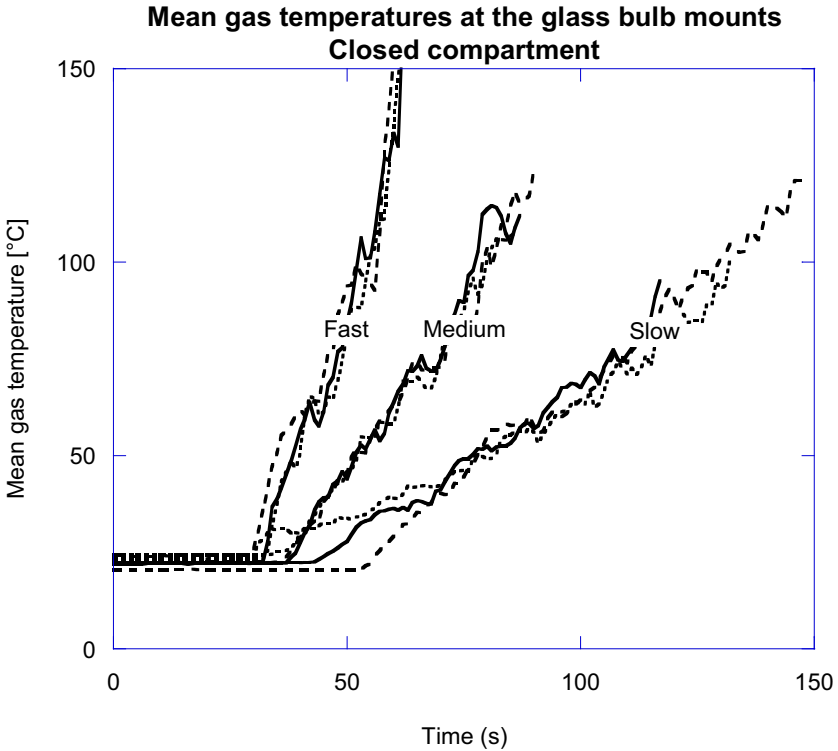
Figure 8. The mean gas temperature (of three measurement points) as measured at the position of the centermost glass bulb on each mount, for each of the three tests at all three fire growth rate scenarios, respectively. Data for the closed compartment.

small range of operating temperatures and RTI's used in the test. Many commercial residential sprinklers are fitted with a 3 mm, 68°C glass bulbs. The residential sprinkler installation practices in NFPA 13D [10] and 13R [11] states that sprinklers installed where the maximum ambient ceiling temperatures do not exceed 38°C (100°F) shall be ordinary-temperature or intermediate-temperature rated, unless the sprinkler may be exposed to conditions such as direct sunlight or heat from specific heat sources. Ordinary-temperature rated sprinklers are defined as sprinklers having a temperature rating between 57°C and 77°C and intermediate-temperature rated sprinkler have a temperature rating between 79°C and 107°C.

Table 3 shows the mean heat release rate upon activation when using 3 mm sprinkler glass bulbs with 57°C or 47°C temperature rating in lieu of 68°C rating, in the tests.

The use of sprinklers with 3 mm, 57°C sprinkler glass bulbs is in line with the recommendations of NFPA 13D and 13R and it appears that heat release rate is in the order of 15% to 30% smaller as compared to the 68°C temperature rating. The reduction in heat release rate is the most noticeable for the open compart-

**Mean gas temperatures at the glass bulb mounts
Open compartment**

Figure 9. The mean gas temperature (of three measurement points) as measured at the position of the centermost glass bulb on each mount, for each of the three tests at all three fire growth rate scenarios, respectively. Data for the open compartment.

ment condition. When using 47°C sprinkler glass bulbs, the fire is in the order of 30% to 50% smaller.

By using a specific fluid, some of the glass bulbs with an actual diameter of 3 mm had response characteristics similar to 2.5 mm glass bulbs. These particular sprinkler glass bulbs are therefore directly interchangeable, e.g. they have the same physical dimensions and mechanical properties as regular 3 mm glass bulbs. Table 4 shows the mean heat release rate upon activation when using "2.5 mm" sprinkler glass bulbs with 57°C or 47°C temperature rating lieu of regular 3 mm glass bulbs with 68°C rating, in the tests.

When using "2.5 mm" 57°C sprinkler glass bulbs, the heat release rate is in the order of 25% to 30% smaller as compared to when using regular 3 mm, 68°C glass bulbs. When using 47°C sprinkler glass bulbs, the fire is in the order of 40% to 50% smaller.

Table 5 shows the mean heat release rate upon activation when using 1.5 mm sprinkler glass bulbs with 57°C or 47°C temperature rating lieu of regular 3 mm glass bulbs with 68°C rating, in the tests. Sprinkler glass bulbs with a diameter as

Fire detectors - all fire scenarios
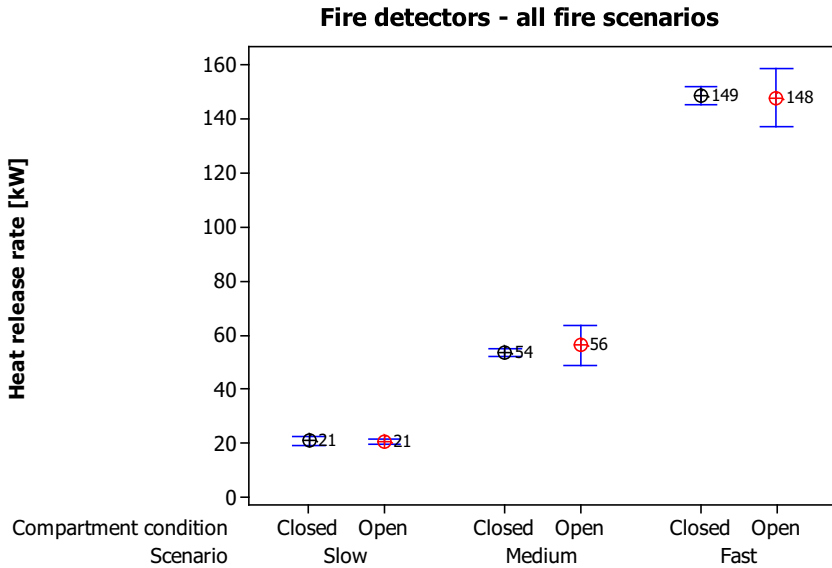
Figure 10.   The mean heat release rates at the activation of the fire detectors for all fire growth rate scenarios and compartment conditions.

Table 3
The Mean Heat Release Rate Upon Activation if Using 3 mm Sprinkler Glass Bulbs with 57°C or 47°C Temperature Rating In Lieu of 68°C Rating

	HRR in closed compartment (kW)			HRR in open compartment (kW)		
Fire growth rate scenario	3 mm, 68°C glass bulbs	3 mm, 57°C glass bulbs	3 mm, 47°C glass bulbs	3 mm, 68°C glass bulbs	3 mm, 57°C glass bulbs	3 mm, 47°C glass bulbs
Slow	52	43 (0.83)	32 (0.62)	90	61 (0.68)	42 (0.47)
Medium	88	77 (0.88)	58 (0.66)	128	96 (0.75)	69 (0.54)
Fast	186	161 (0.87)	134 (0.72)	215	178 (0.83)	138 (0.64)

The ratio of the heat release rates is given in parenthesis

small as 1.5 mm may typically not be used in regular sprinklers due to their lower mechanical strength, however, these bulbs are commonly used for automatic water mist fire protection nozzles.

When using 1.5 mm, 57°C sprinkler glass bulbs, the heat release rate is in the order of 30% to 35% smaller as compared to when using regular 3 mm, 68°C glass bulbs. When using 47°C sprinkler glass bulbs, the fire is in the order of 45% to 60% smaller.

Table 4
The Mean Heat Release Rate Upon Activation If Using ''2.5 mm'' Sprinkler Glass Bulbs with 57°C or 47°C Temperature Rating In Lieu of 3 mm Glass Bulbs with 68°C Rating

	HRR in closed compartment (kW)			HRR in open compartment (kW)		
Fire growth rate scenario	3 mm, 68°C glass bulbs	2.5 mm[a], 57°C glass bulbs	2.5 mm[a], 47°C glass bulbs	3 mm, 68°C glass bulbs	2.5 mm[a], 57°C glass bulbs	2.5 mm[a], 47°C glass bulbs
Slow	52	38 (0.73)	30 (0.58)	90	60 (0.67)	41 (0.46)
Medium	88	66 (0.75)	50 (0.57)	128	90 (0.70)	67 (0.52)
Fast	186	141 (0.76)	118 (0.63)	215	162 (0.75)	123 (0.57)

The ratio of the heat release rates is given in parenthesis
[a] By using a specific fluid, the RTI of the 3 mm glass bulb was similar to a 2.5 mm glass bulb

Table 5
The Mean Heat Release Rate Upon Activation if Using 1.5 mm Sprinkler Glass Bulbs with 57°C or 47°C Temperature Rating In Lieu of 3 mm Glass Bulbs with 68°C Rating

	HRR in closed compartment (kW)			HRR in open compartment (kW)		
Fire growth rate scenario	3 mm, 68°C glass bulbs	1.5 mm, 57°C glass bulbs	1.5 mm, 47°C glass bulbs	3 mm, 68°C glass bulbs	1.5 mm, 57°C glass bulbs	1.5 mm, 47°C glass bulbs
Slow	52	34 (0.65)	24 (0.46)	90	57 (0.63)	34 (0.38)
Medium	88	60 (0.68)	46 (0.52)	128	83 (0.65)	50 (0.39)
Fast	186	120 (0.65)	107 (0.58)	215	149 (0.69)	102 (0.47)

The ratio of the heat release rates is given in parenthesis

The fire detection threshold of the fire detectors was set at a fixed-temperature limit of 40°C. For the activation of a sprinkler system using fire detectors, a temperature limit this low need to be combined with additional fire detection criteria, such as the detection of smoke. However, this feature of the fire detectors was not tested as the propane gas burner generated little smoke. The heat sensors of the detectors typically detected the fire prior to the activation of the first sprinkler glass bulb for the 'slow' fire growth rate scenario. However, for the 'medium' and 'fast' fire growth rate scenarios, some of the sprinkler glass bulbs activated prior to the fire detection. This is specifically noticeable for the fast fire growth rate scenario. The explanation may be a change of the gas flow profile and velocity of the ceiling jet (at the centerpoint of the compartment) with an increase in the fire growth rate. This may make the position of the glass bulbs relative to the ceiling more exposed to the hot flowing gas as compared to the thermal sensors of the fire detectors, especially as the vertical distance from the ceiling to the mid-points of the glass bulbs were slightly less than the vertical distance from the ceiling to

Table 6
The Mean Heat Release Rate Upon Heat Detection of the Fire Detectors As Compared to the 3 mm Glass Bulb with 68°C Temperature Rating and the ''2.5 mm'' Glass Bulb with 57°C Temperature Rating

Fire growth rate scenario	HRR in closed compartment (kW)			HRR in open compartment (kW)		
	3 mm, 68°C glass bulbs	2.5 mm[a], 57°C glass bulbs	Fire detectors	3 mm, 68°C glass bulbs	2.5 mm[a], 57°C glass bulbs	Fire detectors
Slow	52	38	21 (0.40/ 0.55)	90	60	21 (0.23/ 0.35)
Medium	88	66	54 (0.61/ 0.82)	128	90	56 (0.44/ 0.62)
Fast	186	141	149 (0.80/ 1.06)	215	162	148 (0.69/ 0.91)

The ratio of the heat release rates is given in parenthesis
[a] By using a specific fluid, the RTI of the 3 mm glass bulb was similar to a 2.5 mm glass bulb

the heat sensors of the detectors. Another explanation may be the phenomena discussed by Gottuk et al. [12], where the RTI correlation for heat detectors was found to be inconsistent across temperature and velocity test conditions.

The fire detection times of the fire detectors were barely influenced whether the compartment was closed or open, which may be an effect of the combination of a low temperature threshold and the presumably low RTI.

Table 6 shows the mean heat release rate upon fire detection of the fire detectors compared to regular 3 mm glass bulbs with 68°C rating and the ''2.5 mm'', 57°C sprinkler glass bulbs, in the tests. The latter is of interest as this particular sprinkler glass bulb and temperature rating may be a viable option from a practical point of view.

The heat release rate upon fire detection of the fire detectors was in the order of 20% to 60% smaller in the closed compartment and approximately 30% to 80% smaller in the open compartment as compared with the regular 3 mm, 68°C rated sprinkler glass bulb. The relative difference was the largest for the 'slow' and the least for the 'fast' fire growth rate scenario.

Compared with the ''2.5 mm'', 57°C rated sprinkler glass bulb, the heat release rate was in the order of none to 45% smaller in the closed compartment and 10% to 65% smaller in the open compartment, when detected by the fire detectors. Also for this case, the relative difference was the largest for the 'slow' and the least for the 'fast' fire growth rate scenario.

From the data, it appears that the largest benefit from sprinkler system activation by a signal from a combined heat and smoke detector would be associated with a 'slow' or 'medium' fire growth rate inside a larger compartment. For the case the fire develops rapidly inside a smaller sized room, the advantage of activating a sprinkler system by a signal from a combined heat and smoke detector as compared to a thermal activation by a sprinkler glass bulb is less. In practice,

there may also be a certain time delay associated with signal transmission, the opening of valves(s) and the travel time of water in the empty sprinkler piping. In order to benefit from any reduced fire detection and system response time, it is also essential that the coverage area of the fire detectors does not exceed the coverage area of the sprinklers.

10. Conclusion

These tests show that there is a potential for improving sprinkler response times in a residential room fire scenario by using glass bulbs with a lower thermal sensitivity and lower operating temperature than commonly used. It is observed that the nominal operating temperatures of the glass bulbs have a stronger effect on the results than does the RTI, for all the three fire growth rate scenarios. In other words, a reduction of the nominal operating temperature of a sprinkler glass bulb has a larger effect on the speed of response than a reduction of its thermal sensitivity, at least within the relatively small range of operating temperatures and RTI's used in the test.

As an example, the reduction of the temperature rating from 68°C to 57°C of a 3 mm sprinkler glass bulb would result in a fire size that is in the order of 15% to 30% smaller upon activation, all dependent on the fire growth rate scenario and the compartment conditions. A 57°C sprinkler temperature rating is in line with the recommendations of NFPA 13D and 13R, however, a lower temperature rating would not be permitted. When using 1.5 mm, 57°C sprinkler glass bulbs, the heat release rate upon activation is in the order of 30% to 35% smaller as compared to when using regular 3 mm, 68°C glass bulbs. This type of glass bulb and temperature rating is frequently used for automatic water mist fire protection nozzles. However, it should be regarded that the use of lower operating temperatures would require attention during the transportation, installation and use of the sprinklers in order to prevent unintended water discharge. Additionally, the operating sensitivity must be balanced against the probability for operating excessive numbers of sprinklers in a fire. Thinner glass bulbs are also more vulnerable to mechanical damage, which require care during transportation and installation and may demand stringent routines regarding the inspection, control and maintenance of the sprinkler system.

Whether the compartment was fully enclosed or open, e.g. had two walls removed, had a large influence on the time to activation, especially in the 'slow' and 'medium' fire growth rate scenarios. For the sprinkler glass bulbs with the lowest operating temperature, this effect is not as pronounced.

A smoke alarm fitted in the room will provide early warning of a fire and should alert the occupant of a fire. Smoke alarms are mandatory with residential sprinklers. If the smoke alarm was linked to the sprinkler system, early fire suppression would be possible. For these tests, a multi-criteria fire detector was tested. Such a detector would limit the likelihood for false operations as it requires at least two conditions for fire alarm. It was observed that the combination of a fixed temperature threshold of 40°C and smoke (not applied in the tests) would

provide an alarm and potential sprinkler operation considerably earlier compared to the activation of a sprinkler glass bulb for the 'slow' fire growth rate scenario. However, for the 'fast' fire growth rate scenario, the improvement over a sprinkler glass bulb was small, especially in the closed compartment. It was also observed that the fire detection times of the fire detectors were barely influenced whether the compartment was closed or open, which may be an effect of the combination of a low temperature threshold and the presumably low RTI. The use of multi-criteria fire detectors for the detection of fire and activation of a sprinkler system would have practical implications that need to be accounted for, such as the probability for unintended activations, increased system complexity and probably also increased system installation and maintenance costs.

Acknowledgements

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