Physical Characteristics of Residential Sprinklers Water Spray

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Abstract

Purpose / Context - With the development of urban economy, the number of tall and supertall buildings is in- creasing because of high population density, high land price and getting iconic buildings. Small residential units of less than 30 m^2 with an open kitchen are constructed in tall residential buildings. Apart from open kitchen, glass partition is also common because of the constraint from architectural design. Fire hazards in such tall resi- dential buildings have raised public concern. In order to provide better protection of lives and properties in case of fire, provi- sion of residential sprinkler system should be considered as it is not a mandatory requirement for resi- dential premises in many countries. This paper presents the results of experimental tests about the physical characteristics of some residential sprinklers. By conducting a series of tests, including the tests in wind tunnel, tests of spray patterns and tests under controlled fires, valuable information and data were recorded for analysis.

Methodology / Approach - Small propanol pool fires were used in the fire tests to evaluate whether the residen tial sprinkler was able to control the fire.

Results – Physical characteristics of residential sprinkler under different pressures and flow rates have been studied and the findings were presented in this paper. Thermal sensitivity and the activation time of sprinkler heads have been measured and the spray pattern of the sprinkler and resultant water density distribution were discussed in relation to the fire development. Water char- acteristic tests were found useful in determining the operating pressure and flow rate.

Key Findings – It demonstrated that the installation of residential sprinklers could effectively control the fire size and lower the overall fire temperature as well as the heat release rate.

Originality - The residential sprinkler certainly reduces the probability of having fatalities and injuries in domestic fires.

Keywords - Residential sprinkler, tall buildings, fire hazards

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1. Introduction

This paper presents the results of experimental tests about the physical characteristics of some residential sprin- klers. By conducting a series of tests, including the tests in wind tunnel, tests of spray patterns and tests under controlled fires, valuable information and data were recorded for analysis. In Hong Kong, no sprinkler installation is required to be provided in general residential areas. Therefore, there are some suggestions on the necessarity of provision of sprinkler installation in residential areas with safety concerns. The design trendency of residential buildings in Hong Kong is changing. A 30m² residential units with an open kitchen is common in Hong Kong (Chow and Pang, 2011). Apart from small unit, open kitchen and glass partition are also common in luxury hous- es because of architecture design consideration. Also, with the development of urban economy, the number of high-rise buildings and super high-rise buildings is increasingbecause of high population density and land price (Liu et al., 2012). For the fire hazards of the above building structures, it raises concerns on the need of installing sprinkler in residential areas.

Four different types of residential sprinklers were chosen for the tests, they were GL5601 and GL5651 from GLOBE, FIRE SPRINKLER CORPERATION, and Zstx-15 & K-zstx 15 from KUAIDA FIRE SCIENCE AND TECHNOLOGY. In the first set of experiments, Response Time Index (RTI) was measured by the Wind Tunnel Test. It gave the activation time of sprinkler under pressure and flow rate. Sprinkler is used to control the heat release rate. With the help of sprinkler protection, the peak release rates, maximum heat flux and burning dura- tion could be reduced, the system allows more time for people to escape. The survival rate of residents could be increased by about 20 % after installing sprinklers in residential areas (Xin and Huang, 2013).

The residential building differs from other types of buildings on the characteristics of population. There is usually a long delay from starting of the evacuation because the occupants may be asleep or undressed. They are not ready to evacuate when there is a fire. In addition, occupants are reluctant to leave their own properties (Ronchi and Nilsson, 2013). Due to the above mentioned reasons, the suppression for the fire growth is necessary for allowing more time for people to escape. To protect resident from terrible injury or loss of life, it is important to raise the awareness of the fire safety in residential building in Hong Kong. Installation of sprinkler system inside the residential building is one of the approaches since water from sprinkler could dilute the toxic gases and cool down the hot smoke (Chow, et al., 2013). With the intention of controlling a residential fire in a more effective way before small room fills up with toxic smoke, the residential sprinkler is more sensitive to heat than the standard sprinklers (Madrzykowski, 2002). This paper will discuss the feasibility on installing sprinklers in residential areas with supporting data from the experiments.

2. Methodology

Wind tunnel was used to measure the RTI of sprinkler heads. Equations for the calculation of RTI are shown below. In equation 1, τ and ta could be expressed in terms of the time constant of the heat sensing element and the actuation time of sprinkler respectively. In addition, ΔTA and ΔTg could be expressed in terms of the activa- tion temperature of the sensing element (temperature rating) above the initial temperature and the gas tempera- ture above the initial temperature respectively. In equation 2, vg could be expressed in terms of the air velocity.

$$\tau = - ta/(\ln(1-\Delta TA/\Delta Tg) \quad (1)$$

$$RTI= \tau \sqrt{vg} \quad (2)$$

Flow rate, pressure and Water Density Distribution of different sprinkler head model were obtained. The amount of heat taken away by sprinkler is stated as below. Where m' and L could

be expressed in terms of mass flow rate and latent heat respectively. (With the assumption that sensible heat is ignored)

$$Q = m' \times L \quad (3)$$

Equations for heat release rate (HRR) of a pool fire are shown as below. Where mr and $\Delta Hc,eff$ could be ex- pressed in terms of mass loss rate in kg/s and the effective heat of combustion in MJ/kg respectively. The effec- tive heat of combustion of 2-propanol is 30.11 MJ/kg.

$$Q = mr\Delta Hc,eff \quad (4)$$

The results obtained by the strain gauge and the thermocouple tree would be compared with the results obtained by the measurement of water characteristic test. This comparison would show the relationship between the combustion performance and the water characteristic of residential sprinkler. Also, it would show how it controls the fire size and whether it is capable to extinguish the fire.

The provision of residential sprinkler system is suggested to be provided for whole premises in- cluding the open kitchen, illegal glass partition, super tall building as well as the store room. The fire hazards behind the above residential areas have been discussed (Chow and Pang, 2011; Chow et al., 2013; Chow, 2014; Woo et al. 2015). The comparison of the overseas codes and the application of the overseas codes into Hong Kong have been made. Understaing the limitations of the application and the installation of sprinkler in residential areas could facilitate the fire fighters to carried out their rescue works which have been discussed in other literatures (British Automatic Fire Sprinkler Association, 2008; Cote et al., 2008; National Fire Protection Association, 2013a, 2013b).

3. Experiments

As a result, 3 sets of experiments had been conducted (Chan 2015). For the wind tunnel test in Figure 1, it was the first set of experiments used to simulate the ceiling jet of smoke. The tunnel was constructed by 1.2 mm mild steel sheet with the dimensions 3 m long, 1.6 m high and 0.7 m wide. The tunnel air temperature was controlled to respond to any programmed change immedi- ately with its relatively low thermal mass. When the air was blown by the centrifugal fan with a specific frequency, the inlet air was expected to pass through the heating section with finned air heater. The heated air entered the contraction section and passed the working section before reaching the outlet. Finally, the RTIs of 4 different types of sprinkler heads were obtained.

The second set was the measurement of the water density distribution (WDD). About 64 water buckets were used to collect the water projected from sprinkler head in array of 4m x 4m. By the measurement of the volume of each bucket, the WDD contour could be drawn for each type of sprinkler. The photos of distrubition patterns were also be taken after the actuation of sprinkler heads under specified pressure flow and flow. With such information, the heat to be taken by the water spray could also be calculated.

The final set of experiment was the measurement of strain gauge and the temperature from ther- mocouple tree in Figure 3 & Figure 4. A pool fire was ignited on a weight balance which is con- nected with the strain gauge and the data logger to present the mass change of the 2-propanol in terms of voltage during the combustion. At the same time, the thermocouple tree with 4 measurement points at vertical position, i.e. 30cm, 60cm, 84cm and 120cm, on top of the pool fire was set. The sprinkler heads were actuated when the temperature reached their operating temperature. The data had been recorded for the first 7 mins and some photos were taken for analysis.

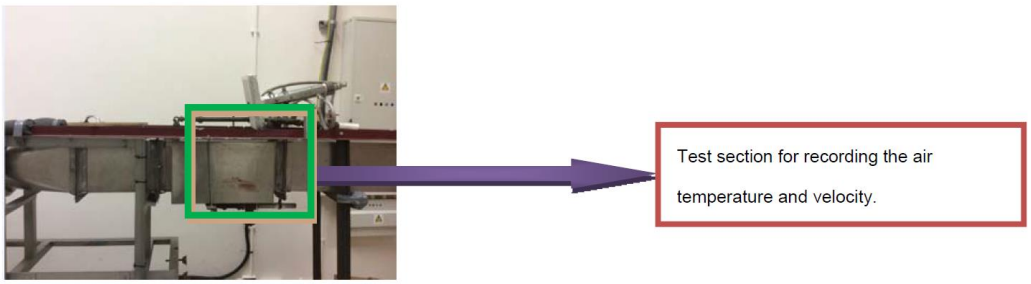


Figure 1 Setting up of Wind Tunnel Test

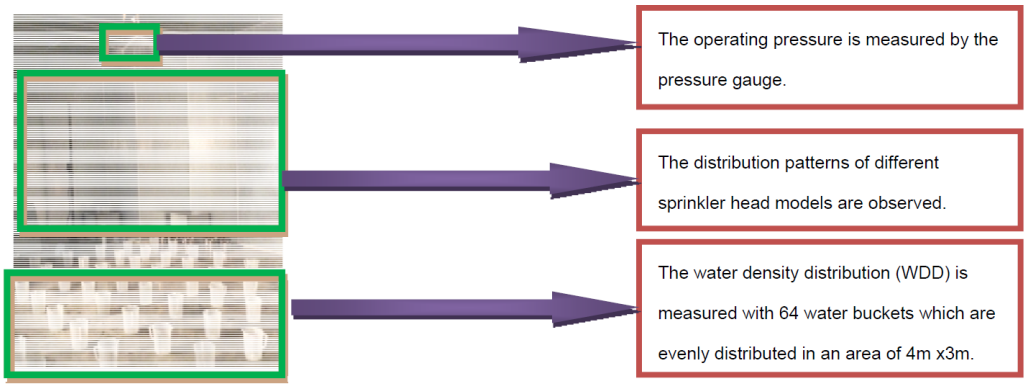


Figure 2 Measurement of Distribution Patterns

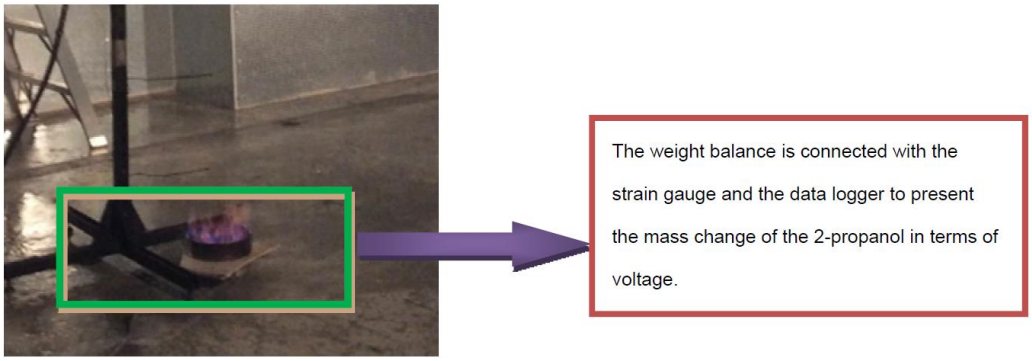
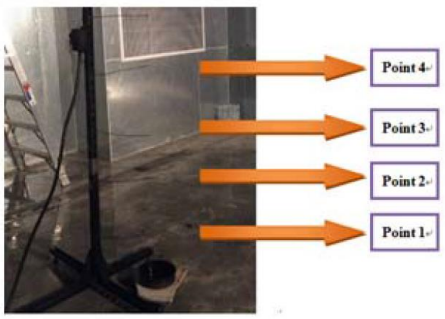


Figure 3 Measurement by Strain Gauge



Points	Distance from the detected point from the fire (cm)
1	30
2	60
3	84
4	120

Figure 4 Setting up of Thermocouple Tree

4. Results and Discussion

Fast response type sprinkler refers to the sprinkler with RTI less than 50 (meters-seconds)$^{1/2}$. For the residential building in Hong Kong with extreme high-occupant density, it is necessary to adopt the fast response type sprin- klers to provide better protection for high life risk premises. From the results of Wind Tunnel Test at Table 1, GL5601 and K-zstx 15 are fast response type sprinklers while GL5651 and Zstx-15 are standard type. Fast re- sponse type sprinklers are installed for the areas with greater fire hazard so that it is able to actuate the system faster in order to allow people the leave in the early fire stage.

Table 1: Summary of the results from Wind Tunnel Test

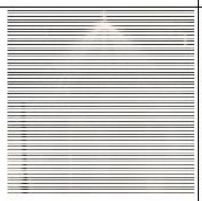
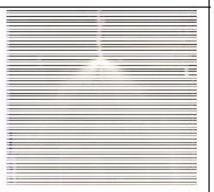
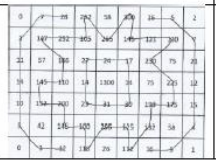
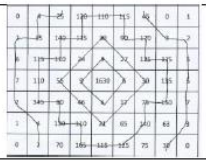
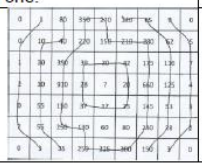
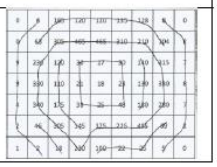
Sprinkler head Model	Data	Gas temperature(°C)		Average
		100	120	
GL5651	**Time Constant**	41.25	41.85	**41.55**
	Response Time Index (RTI) (ms)$^{1/2}$	58.34	59.18	**58.76**
GL5601	**Time Constant**	23.	15.55	**19.63**
	Response Time Index (RTI) (ms)$^{1/2}$	33.51	21.98	**27.75**
Zstx-15	**Time Constant**	4	43.05	**43.03**
	Response Time Index (RTI) (ms)$^{1/2}$	60.82	63.88	**62.35**
K-zstx 15	**Time Constant**	24.57	15.55	**20.06**
	Response Time Index (RTI) (ms)$^{1/2}$	34.75	21.98	**28.37**

Compared the heat release rate and the total amount of heat released in the fire tests (Table 3), it was noted that the heat release rate (HRR) was smaller at the tests with sprinkler installation. The actuation of system could reduce the speed of fire spread and allow more time for occupants to escape. In addition, it was found that the total amount of heat release for the sprinkler model GL5651 and GL 5601 were smaller than that of the scenario without the sprinkler installation. This implied that they extinguished the fire before the fire consumed all the fuel (2-propanol). The spray pattern of the sprinkler models are accounted for the phenomenon. For the sprinkler model GL5651 and GL 5601, the water was mainly discharged to the area just beneath the sprinkler heads.

The burning period for 300 ml pool fire of 2-propanol was **432s** when there was no sprinkler installation. For the fire stage period from 1 minute to 5 minutes (Table 3), the air temperature was above 300 °C for the vertical distance was 15cm above the fire. It lasted for about **4 minutes**. For sprinkler model GL5651 and GL5601, the water was mainly distributed to the centre according to the water characteristic results. From the pool fire test results, it revealed that the burning period could be reduced to the **half** of the test without sprinkler installation. From the thermocouple tree's results, it was observed that the air temperature could be controlled **below**

100°C at a vertical distance of 15cm above the fire. As the water distribution is likely at the centre (Table 2), it is suitable to be used at the location with concentrated fire load such as open kitchen.

Table 2: Summary of the results from Water Characteristic Test

Sprinkler models	GL5651	GL5601	K-zstx15	Zstx15
Pressure(bar)	2	2	2	2
Flow rate(L/s)	0.444	0.442	0.440	0.440
Heat taken away (kJ/s)	1003	999	994	994
Distribution pattern				
Description on the distribution pattern	Water was mainly distributed in the water buckets around the middle one.	Water was mainly distributed in the water buckets around the middle one.	Water was mainly distributed in the water buckets to the side areas. Therefore, very small amount of the water was collected by the water buckets around the middle one.	Water was mainly distributed in the water buckets to the side areas. Therefore, very small amount of the water was collected by the water buckets around the middle one.
WDD Contour				

(Remark: The specific latent heat of vaporization of water is 2260kJ/kg)

For sprinkler model K-zstx15 and Zstx-15, the water was mainly distributed to the side areas due to its deflector from the water characteristic results. From the pool fire test results (Table 4), it was found that the burning period was slightly longer than the case without the sprinkler installation. As water discharged to the sides which could lower the overall fire temperature in the surrounding and the cooling effect by the water projected directly on the pool fire, the heat release rate was decreased accordingly. From the thermocouple tree's result, it was observed that the air temperature in different periods of times was **lower** than the case without the sprinkler installation. In addition, the air temperature above 300 °C at the vertical distance of 15cm above the fire **shortened** to about **2 minutes**. All the above could increase the rescue time for the fire fighters and increase the evacuation time for the occupants by controlling the fire. Since the water distribution was not concentrated at the centre, it is suitable to be used at the location with fire load which is evenly distributed such as store room.

Table 3: Summary of the results from Pool Fire Test (Strain gauge) with 300ml of 2-propanol used

Time(s)	Without the sprinkler installation	Sprinkler models			
		GL5651	GL5601	K-zstx 15	Zstx-15
5s(Just before the sprinkl actuated)					
30s					
1min					
3min					
5min		Fire is extinguished	Fire is extinguished		
7min		Fire is extinguished	Fire is extinguished		
Burning Period	7mins12s	3min07s	4min41s	8mins 19s	8mins
Mass loss rate (kg/s)	0.00052	0.00051	0.00050	0.00045	0.00047
Heat Release Rate (kW)	15.61	15.45	15.20	13.53	14.04
Total amount of heat released(kJ)	6743	2890	4271	6740	6738

Table 4: Summary of the results from Pool Fire Test (Thermocouple tree)

Fire stage at different period of time		Sprinkler head models				
		Without the sprinkler installation	GL5651	GL5601	Zstx-15	K-zstx 15
0s	Point 1	18	18	18	18	18
	Point 2	18.4	18.4	18.4	18.4	18.4
	Point 3	19.1	19.1	19.1	19.1	19.1
	Point 4	19.4	19.4	19.4	19.4	19.4
30	Point 1	260.4	49.8	66.4	254.5	262.1
	Point 2	115.2	42.3	54.1	106.4	105.6
	Point 3	48.1	31.6	30.2	62.6	61.9
	Point 4	56.7	32.4	39.6	48.9	48.1
1 min	Point 1	**335.8**	64.1	57.8	**488.8**	**448.8**
	Point 2	115.1	41.7	52.5	125.1	138.2
	Point 3	65.8	29.9	42.7	73.9	75.8
	Point 4	58.3	27.4	44.8	46.3	47.5
3 min	Point 1	**585.5**	37.2	47.9	**322.2**	**436.5**
	Point 2	148.7	25.6	35.7	179.9	180.4
	Point 3	81.9	23.3	30.7	107.3	106.6
	Point 4	65.1	22.5	32.2	63.8	62.7
5 min	Point 1	**495.5**			195.9	270.1
	Point 2	134.8	Fire is extinguished	Fire is extinguished	163.3	98.3
	Point 3	76.5			88.7	51.8
	Point 4	66.3			66.4	43.4
7 min	Point 1	219.6			172.9	200.9
	Point 2	90.9	Fire is extinguished	Fire is extinguished	105.5	73.1
	Point 3	55.9			59.8	39.3
	Point 4	50.8			55.1	37.5
Burning Period		**7mins12s**	**3min07s**	**4min41s**	**8mins 19s**	**8mins**

Remark: The temperature is in ^{o}C. The highlighted figures in red refer to air temperatures above 300^{o}C.

5. Conclusions

Residential areas in Hong Kong that require the installation of sprinkler was identified. It demonstrated that the installation of residential sprinklers could effectively control the fire size and lower the overall fire temperature as well as the heat release rate. Different sprinkler heads have different deflectors leading to different WDDs. Therefore, the application of the sprinkler in the residential areas should be in accordance with the scenario. From the results of the study, the sprinkler head model **GL 5601** is one of the suitable sprinklers to be applied in Hong Kong since it is a fast response type sprinkler and it is able to extinguish the domestic fire promptly.

It is believed that installation of residential sprinkler can protect lives and reduce property losses. In case of fire, the occupants could be alerted by the fire alarm system and escape from the premises in early stage. In the meanwhile, the fast response type sprinkler could be actuated and put out / control the fire accordingly. For the new high-rise residential building, the system should be considered to be installed as a standard requirement. The residential sprinkler will certainly reduce the probability of having fatalities and injuries in domestic fires. From economic point of view, the protection by the system could mitigate the damages or losses in case of fire, particularly in premises with high property value / high rental value like Hong Kong. Other benefits, like reducing the water usage and environmental issues, should also be addressed

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