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Protection of glazing in fire separations by sprinklers

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ABSTRACT

To overcome the problems with the use of glazing in fire separations without compromising fire safety, the Institute for Research in Construction (IRC), National Research Council of Canada (NRCC), in collaboration with industry partners, has developed a method of protecting window assemblies using tempered and heat-strengthened glass by providing a water film on the assembly. This method incorporates an active sprinkler system to enhance the minimal passive fire protection normally afforded by the glazing.

Two problems arise when considering glazing exposed to fire. The first is that differential thermal stresses may fracture the glass. The second is that, even if the glass remains in place, transmission of thermal radiation through it may exceed the level which can be safely tolerated by combustible materials on the other side. Both of these problems can be avoided by spraying sufficient water on the glass early in the fire. The water spray forms a film which ensures that the heat build-up in the glass occurs at a uniform rate and does not become excessive. The water film also attenuates the radiant heat.

This paper briefly describes the test facility and the test method which has been used to investigate the effectiveness of the special sprinkler systems. It provides the results of the test series to determine the maximum window width which can be protected by a single sprinkler, and the use of a multi-sprinkler system for the protection of very wide windows with and without mullions. The paper also deals with the effectiveness of ceiling-mounted sprinklers. Evaluation of all cases is based on the two principal criteria for sprinkler protection of glazing materials exposed to fire; early activation and sufficient water spray.

INTRODUCTION

Designers and building owners are increasingly demanding the use of glazing in fire-rated walls for aesthetic, security and economic reasons. Since ordinary window glass shatters after only a few minutes exposure to fire, building regulations restrict the use of glazing in fire separations. To overcome the problems with the use of glazing in fire separations without compromising fire safety, the Institute for Research in Construction (IRC), National Research Council of Canada (NRCC), in collaboration with industry partners, has developed a method of protecting window assemblies using tempered and heat-strengthened glass by providing a water film on the assembly. This method incorporates an active sprinkler system to enhance the minimal passive fire protection normally afforded by the glazing.

Tests conducted at the National Fire Laboratory (NFL) of IRC indicate that, under specific conditions, tempered or heat-strengthened glass, protected by a sprinkler system, will remain intact for more than an hour. The effect of sprinkler activation time and sprinkler water flow rate on the effectiveness of dedicated sprinkler systems for protecting single window units has already been demonstrated. There has, however, been a strong demand for information on the use of sprinkler systems to protect multi-window systems and very wide windows with and without mullions. The use of ceiling-mounted sprinklers to protect windows is another area where the technology has yet to be validated.
Successful sprinkler protection of glazing systems exposed to fire depends on two primary factors: early activation and sufficient water spray. Sprinkler activation time is the first important criterion for the performance of a glazing system protected by water spray. The sprinkler must actuate early enough to prevent significant temperature increase on the glass. A substantial delay in applying water may be counterproductive, as the application of cold water to preheated glass may cause premature failure. Once activated, sufficient water must be uniformly sprayed over the glass and frame to prevent large temperature gradients. In all cases, the upper corners of the glazing are the most vulnerable portions because, with low sprinkler pressure, sufficient water may not be delivered to these areas, resulting in thermal stresses and possible failures.

This paper briefly describes the test facility and the test method which has been used to investigate the effectiveness of these special sprinkler systems. It provides the results of the test series to determine the maximum window width which can be protected by a single sprinkler, and the use of a multi-sprinkler system for the protection of very wide windows with and without mullions. The paper also deals with the effectiveness of ceiling-mounted sprinklers.

**TEST FACILITY AND PROCEDURE**

The NRCC full-scale tests were performed using a burn room with a floor area of 3.6 m x 3.3 m and with a 3.3 m ceiling height. A detailed description of the test facility was given in a previous paper.

The window assemblies were mounted in one wall of the burn room. A 25 mm space below the window assembly at floor level allowed surplus water to drain from the room. Glass temperatures were measured at several locations on both the exposed and unexposed sides using chromel-alumel thermocouples bonded to the glass with clear epoxy resin.

Fire exposure was provided by a linear propane burner installed on the floor adjacent to the west wall of the test room. Combustion air was blown into the burn room through a perforated steel duct located beneath the propane burner. Combustion products and steam were withdrawn naturally through two stacks with 0.6 m x 0.45 m cross-sections located in the north and south walls. To retain the hot gases in the room while removing cooler steam, the exhaust stack inlets were located near the floor.

The fire exposure to the glazing assembly was based on a predetermined fire load. A preliminary burn test was conducted to determine the propane flow required to maintain the average enclosed test room temperature as close as possible to the standard time-temperature curve without sprinkler operation. The room temperature was measured at six locations by Type K thermocouples. The pre-calibrated propane flow was used for the tests with sprinkler protection. The only sprinklers operating during the tests were those used to protect the window assembly.

A Beckman Hydrocarbon Analyzer, pre-calibrated for propane, was used to measure the propane concentration in the exhaust stack. The hydrocarbon level in the exhaust stack was less than 0.05% throughout the tests indicating that the combustion efficiency was not significantly affected by the water vapour accumulation in the room. Therefore, the total heat release in the test room was not decreased by the action of the water spray, and the window assembly with the water spray provided by the sprinklers was subjected to essentially the same fire load as in the non-sprinklered calibration test.

**TEST RESULTS**

**Maximum Coverage by a Single Sprinkler**

NRCC's previous study showed that tempered or heat-strengthened glass protected by a sprinkler system will remain intact for more than one hour. In that study, a fast response window sprinkler was installed at the top centre of a window, however, the maximum width of the window considered was limited to 1.8 m.
NRCC continued the experimental study to determine the maximum width of window which could be protected by a single sprinkler. Fast response window sprinklers with a temperature rating of 74°C and a Response Time Index (RTI) of 22.7 m/s² were used. A sprinkler was installed in such a way that it represented an installation at the top centre of a window assembly. The centreline of the deflector was typically 50 mm below the top frame and the deflector was positioned 13 mm from the glass. The sprinklers were mounted horizontally, with the water spray directed primarily onto the glazing and the frame. Results of the tests are shown in Table 1.

The window assembly used in Test #1 (Table 1) was a 2.6 m wide tempered glass window in an aluminum frame. The sprinkler was located at the top centre of the window on the fire exposed side. Under fire exposure equivalent to standard time-temperature curve, the sprinkler activated at 20 s and with sprinkler water pressure of 172 kPa (25 psi), the sprinkler provided enough water spray protection on the window assembly for 2 hours. The water spray was not sufficient to cover all of the surface of the 2.6 m wide window, especially near the top corners of the window, however, these top corners were provided with some protection by water drippings from the top window frame, and there were no dry areas on the glass surface. The window maintained its integrity for 2 hours under fire exposure. The glass and frame temperatures on both the fire exposed (with water protection) and unexposed sides were well below 100°C for the duration of the test.

In Test #2, 2 panes of 0.9 m wide tempered glazing were butt-joined with a 20 mm wide flat rubber gasket to make a 1.8 m wide window assembly. This window assembly was exposed to fire and protected by a single dedicated sprinkler located at the top corner of the window. This would simulate a 3.6 m wide window system with a sprinkler located at the top centre of the window. The water pressure for the sprinkler was maintained at 145 kPa (21 psi). The water spray pattern was good in most of the areas, except at the top corner of the glazing where the area was only wetted by intermittent spray. Dry spots appeared in the area at 15 min and increased in size as the test progressed. The test lasted 60 min without breakage. The glazing temperatures on most of the exposed side were under 100°C, however, the temperature at the top corner, which was dry during the later stage of the test, increased to 350°C by the end of the test.

In Test #3, a 10 mm deep mullion was used to join the two panes of glass in the window system. There was no significant difference in the spray pattern between Test #2 and Test #3 and this test also lasted 60 min without breakage.

In Test #4, a 25 mm deep mullion was used between the two panes of glass. Even in the early stages of the test, the glazing on the side of the mullion away from the sprinkler was hardly wetted and the top portion was mostly dry. The glazing temperatures on the lower portion were below 100°C, however, the glazing temperature at the top portion was above 100°C and increased steadily to 500°C at 23 min at which time the glazing shattered.

In Test #5, a 3 m wide and 0.7 m high tempered glass pane was installed in the test room with a sprinkler located at the top of the glazing, 2 m to the left of the right side edge. This configuration simulated a 4 m wide window protected by a sprinkler located at the top centre of the window. In the early stages of the test, the water spray was adequate, except on the far right side where water spray was intermittent at the top corner and the water film was very thin in the lower region on the right side. At approximately 20 min into the test, a dry spot of approximately 15 cm by 15 cm appeared at the top right corner. This dry spot increased in size to 25 cm by 25 cm at 40 min into the test. At 45 min, the top corner was completely dry, however, the glass withstood the fire exposure for 60 min without breaking. In areas reached by the water spray, the glazing surface temperatures on the exposed side were under 100°C. The temperature at the top corner, not reached by the water spray, rose to 400°C by the end of the test.

In Test #6, the same glazing system as in Test #5 (3 m wide and 0.7 m high) was used, except that the sprinkler was located at the far right corner of the window. This configuration simulated a 6 m wide window protected by a sprinkler located at the top centre of the window. Even in the early stages of the test, the top left corner of the glazing was hardly wetted. At 13 min, a dry area appeared on the left edge. At 15 min, the tempered glass shattered. The glazing temperatures on
the lower portion were below 100°C, however, the glazing temperature at the upper corner of the
window was increasing steadily to 500°C at 15 min when the glazing shattered.

These test results showed that a single dedicated window sprinkler installed at the top centre will
provide protection to a tempered glass window for up to 2.5 m wide. In the tests on 3.6 m and
4 m wide windows, the sprinkler provided protection for 60 min, however, there were dry spots
appearing on the glazing surface during the tests. The glazing temperature measurements showed
that the glazing was reaching the limits of thermal stress during the 60 min test.

Multi-Sprinkler Interaction

To protect a wide glazing assembly from fire exposure, more than one sprinkler may have
to be used. However, in a multi-sprinkler situation, the activation times of the second and
subsequent sprinklers may be adversely affected by the spray from the adjacent operating
sprinkler.

A series of tests was conducted to study the interaction between two adjacent sprinklers. Cases of
very wide window without a mullion between the sprinklers and with centre mullion between the
sprinklers were considered. Mullions are normally provided when several windows are set side by
side. The sprinklers used in the tests were the same special fast response window sprinklers used
in the previous series with a temperature rating of 74°C and an RTI of 22.5 m²/s².

The sprinklers were installed at the top of the window, just below the top frame either 1.8 m or
1.5 m from each other. The activation times of the second sprinkler were measured with adjacent
sprinklers operating. The test results are shown in Table 2. The test results indicate that, when
sprinklers were located 1.8 m apart, the second sprinkler activated in less than 35 s for both
172 kPa and 345 kPa sprinkler pressure, if there was a centre mullion of more than 5 cm depth
located between the sprinklers. In the case with no mullion between the sprinklers, the second
sprinkler activated at 17 s for a sprinkler pressure of 172 kPa, however, when the sprinkler
pressure was 345 kPa, the second sprinkler did not activate during a 60 min test in one case and
activated at 25 min 38 s in another.

When the sprinklers were located 1.5 m apart with a mullion of at least 5 cm depth between them,
the second sprinkler activated in less than 40 s for both 172 kPa and 345 kPa sprinkler pressure.
When there was no mullion between the sprinklers, the second sprinkler activated at 7 min 3 s for a
sprinkler pressure of 172 kPa, and did not activate at a sprinkler pressure of 345 kPa during a 60
min test. These tests indicate that, in a multi-sprinkler scenario, if there is a centre mullion (of
5 cm depth minimum) between the sprinklers, the influence of water spray from the adjacent
sprinkler will not be significant and the second sprinkler will activate in time to protect the glazing
system. In the scenario without any mullion between the sprinklers, the sprinkler activation time
of the second sprinkler could be delayed significantly due to the water spray from the adjacent
sprinkler, depending on the distance between the sprinklers and the water pressure. This activation
delay may cause failure of the glazing system.

To study the impact of sprinkler activation delay on the glazing performance for a wide window
without a centre mullion, several multi-sprinkler protected window systems were tested. The test
results are shown in Table 3. In Test # 1, 3 panes of 1.0 m wide and 1.45 m high tempered glass
were put together side by side with a 20 mm wide flat rubber gasket between them to form a butt
joint. Two standard response sprinklers (with a temperature rating of 74°C and RTI of
138 m²/s²) were installed at the top of the window system, 2 m apart. One sprinkler was
located at the top right corner and another was located at the top, 2 m away from the first, between
the second and third glass pane. This represented a wide window system protected by multi-
sprinklers located 2 m apart.

In the test with one sprinkler operating (with water pressure of 145 kPa), the water film protection
on the mid-portion of the glazing was good, however, the far side of the window was wetted
mostly by fine water mist and had some dry spots. At approximately 10 min, the extreme end of
the glazing was completely dry. The second sprinkler activated at 12 min 50 s, and the glazing
shattered from the thermal shock of the water spray. The highest temperature was recorded at the top corner of the window on the exposed side and reached approximately 400°C just before the second sprinkler activated.

A second test on the same scenario was conducted using fast response sprinklers with temperature ratings of 74°C and RTIs of 22.7 m/s². The second sprinkler operated at 5 min 41 s, and the window system withstood the thermal shock and maintained its integrity. The glazing temperatures at most locations were below 80°C, except at the top corner area of the window where temperature rose to 250°C just prior to the second sprinkler activation.

Thermocouples were attached at the deflector of the second sprinkler to measure the temperatures of the sprinkler which could be used to estimate sprinkler activation times. The mean temperature (with temperature time-fluctuations of ±5°C) of the second sprinkler head rose to approximately 70°C at 5 min, then jumped abruptly to above 90°C for 41 s until the second sprinkler activated. The temperature of the sprinkler mentioned here was the mean temperature, as the actual temperature was fluctuating between 70 and 80°C. Also, since temperatures were being measured at the deflector, the temperature at the fusing element was probably slightly higher because it was a little further away from the glazing and thus received less water spray from the first sprinkler.

In Test #3, a window configuration, simulating a window system with a 2.5 cm centre mullion protected by two fast response sprinklers 2 m apart, was tested. With one sprinkler operating, the water spray wetted its glass pane with substantial water film and wetted the adjoining pane with intermittent water film. Two dry spots appeared at the top corners of the adjacent pane. The glass temperatures at the top corners of the glazing, which were mostly dry during the test, rose to 240°C at 6 min 30 s. The second sprinkler activated at 6 min 30 s and the glazing withstood the thermal shock of the water spray from the second sprinkler. The exposed side glass temperatures at other locations were below 80°C by water spray from the sprinkler. The temperature of the second sprinkler head was below 70°C until 6 min when the temperature rose abruptly to above 150°C and the sprinkler activated. This was probably the result of the evaporation of water mist reaching the second sprinkler. Without wetting, the second sprinkler temperature rose sharply.

Using the same window assembly, a series of tests was conducted in which the second sprinkler was activated manually at different times to study the critical time of second sprinkler activation at which the glazing would withstand the thermal shock of the water spray. In Test #5, the second sprinkler was activated at 9 min, and the glazing withstood the thermal shock and maintained its integrity. The glazing temperature near the top corner, which was almost dry at 9 min just before the second sprinkler was activated. In the next test, the second sprinkler was activated at 10 min, and as soon as the water spray hit the glazing, the glazing shattered. The maximum glazing temperature at the top corner reached 375°C at 10 min, just before it shattered. In these tests, the temperature history of the second sprinkler shows that the second sprinkler would have activated between 6 and 7 min.

Instead of using a window made of multi-panes, one large pane of tempered glass (3 m wide without any joint or mullion) was used in tests to study the effect of sprinkler activation delay on such an assembly. The first sprinkler operated early in the tests and the second sprinkler was activated manually at different times to study the effect of thermal shock from the second sprinkler water spray on the hot glazing. The two sprinklers were located at the top of the window, 2 m apart.

In Test #9, the glazing temperature near the left top corner increased steadily even with the first sprinkler operating because the top corner area was not well wetted. The maximum glazing temperature at that corner reached approximately 350°C at 10 min into the test. When the second sprinkler was activated manually, the glazing withstood the thermal shock and maintained its integrity. In Test #10, the second sprinkler was manually activated at 11 min at which time, the glazing temperature at the left top corner had reached approximately 400°C. When the second sprinkler was activated, the glazing shattered from the thermal shock of the water spray. The
temperature history of the second sprinkler showed that it would have activated between 5 and 7 min.

**Ceiling-Mounted Sprinkler Protection**

The use of ceiling-mounted sprinklers to protect glazing assemblies is gaining interest from building designers since such sprinklers are considered to be more pleasing aesthetically and for cost considerations. The question of whether a ceiling-mounted sprinkler would activate early enough and also whether water spray from the ceiling-mounted sprinkler would provide sufficient protection for glazing assembly exposed to fire needed to be answered, however, before the system could be considered for practical applications.

Tests by Beason\(^3\) showed that a localized small fire near the glazing in such a scenario could produce failure before sprinklers are activated. Subsequent tests carried out by NRCC\(^1\) indicated that ceiling-mounted sprinklers, both standard and fast response sprinklers, would not activate in time to protect tempered glazing from a small fire located adjacent to the glass. This limited the use of ceiling-mounted sprinklers in protecting glazing assemblies. Ceiling-mounted sprinklers can, however, be used to protect a glazing assembly in those cases where the base of the glazing is at least 1 m above the floor. In such instances, the chances of having a small localized fire impinging on the glazing are small, and thus the system would not be expected to face this challenge.

A study was carried out to examine the protection of fire-exposed tempered glazing systems with ceiling-mounted sprinklers. In the ceiling-mounted sprinkler protection case, there are three configuration parameters which affect the sprinkler water spray onto the glazing surface; window sill depth, sprinkler height, and sprinkler distance. The window sill depth is the depth of the top frame and affects the water spray from a ceiling-mounted sprinkler to the top of the glazing. The sprinkler height is the height of the ceiling sprinkler above the top of the glazing. The sprinkler distance is the distance between the sprinkler and the glazing surface. A series of sprinkler spray pattern tests was conducted with a sprinkler pressure of 138 kPa, for various combinations of window sill depth, sprinkler height and sprinkler distance. The range of each parameter considered was: sill depth 5 cm to 25 cm, sprinkler height 5 cm to 60 cm and sprinkler distance 0.3 m to 1.8 m.

The water spray pattern on the glazing system was examined in each spray pattern test. It was noted that there were three distinct regions on the glazing surface based on spray conditions; dry areas, wet areas and good water flow areas. A dry area is an area where the surface was dry most of the time, and occasional water droplets or mist reached the area and quickly evaporated. Such areas were usually located at the very top and at both top corners of the window. A wet area was an area where the water spray was intermittent and had many water droplets sitting on the surface, instead of a continuously flowing water film. These areas were located on the upper portion of the window. A good water flow area was where most of the sprinkler spray was directly impinging and had a continuous flowing water film uniformly on the glazing surface. It covered most of the mid and lower portion of the window.

The spray test results seemed to indicate that, with ceiling-mounted sprinkler protection, the chance of glass breakage from fire exposure increased generally with an increase in sill depth, an increase in sprinkler height, and an increase in sprinkler distance. This is based on the size of the dry area for each configuration, because, as the dry area increases, there is an increased probability of glass breakage from thermal stress. Each configuration parameter is not independent of the other. For example, in some cases, increased sprinkler distance may not increase the chances of glass breakage for a specific sprinkler height but it may for another.

In the spray tests, the largest dry area was obtained in the configuration with a 25 cm sill depth. Other cases where large dry areas appeared were with a 15 cm sill depth with heights of 30 cm and 45 cm. In both cases, the sprinkler distance was 60 cm. For these conditions, full-scale fire tests were conducted on a 1.8 m wide window system to determine the effectiveness of the sprinkler location. A 1.8 m wide and 1 m high tempered glass window was exposed to fire equivalent to the standard time-temperature curve\(^2\), and was protected by a ceiling-mounted sprinkler with sprinkler
pressure of 138 kPa. The results indicated that there were dry areas at the top of the window, however, these areas were wetted occasionally by water droplets and fine water mist from the sprinkler spray which quickly evaporated. These occasional water droplets had some cooling effect on the surface. Toward the later stage of the test, dry areas appeared at the top corners and this area grew in size with time. The sprinkler water spray protection was, however, good enough to provide 1 hr fire protection on the glazing in the tests.

Another test was conducted to examine whether a ceiling-mounted sprinkler could provide fire protection on a window system which was wider than 1.8 m. A 2.6 m wide and 1.5 m high tempered glass window was chosen. The sill depth of the window was 0.1 m and a fast response pendant-type sprinkler was mounted at the ceiling 0.3 m above the top of the window and 0.3 m away from the glazing surface. The sprinkler pressure was 172 kPa. The sprinkler activated at 17 s and provided good water spray to most of the glazing surface. There were several dry areas; a small strip at the top and at both top corners. The dry area at the top corners grew in size with time to a maximum of 0.3 m x 0.6 m. The temperature at this location increased with time to a maximum value of 325°C at 60 min. The sprinkler spray, however, provided enough protection for the window system to maintain its integrity for the 1 hr test duration. These results show that, when a ceiling-mounted fast response sprinkler is located at an ideal position (0.3 m away from the glazing surface and 0.3 m above the top of the window with a minimum window sill depth), the sprinkler water spray can provide sufficient protection for a tempered glass window with a maximum width of up to 2.6 m for at least 1 hr.

The delays in sprinkler activation due to adjacent sprinkler operation were studied for the ceiling-mounted case. Two sprinklers were mounted 1.8 m apart at 0.3 m away from a window system which measured 2.6 m wide and 1.5 m high. The first sprinkler was actuated manually at 5 s and the activation time of the second sprinkler noted. Several sprinkler pressures were used and the results shown in Table 4. The second sprinkler activation time increased with an increase in sprinkler pressure, however, even in the 517 kPa case, the second sprinkler activated at 24 s which was well within the time limit of protecting the glazing from the fire exposure. The tests indicate that when multi-sprinklers are used in a ceiling-mounted configuration (1.8 m apart) to protect a multi-window system, sprinkler activation delays due to adjacent sprinkler operation is not a problem.

DISCUSSION

In the series of tests to determine the maximum width of window which could be protected by a single sprinkler, test results showed that a single dedicated sidewall window sprinkler installed at the top centre provided protection for a tempered glass window up to 2.6 m wide. In the test with a 2.6 m wide window with single sprinkler protection, the water spray from the sprinkler covered all surfaces of the window and frame with good water film flow on the glazing surface. Glazing temperatures reached steady conditions in less than 10 min and the window system maintained its integrity for the 2 hr test duration. For the 3.6 m wide and 4 m wide windows, the window system did not fail during the 60 min test, however, there were dry spots appearing on the glazing surface during the tests. The glazing temperature measurements showed that the glazing was reaching the limits of thermal stress during the 60 min test. The protection of a wide window by a single sprinkler, especially at the top corner, is very sensitive to the water spray pattern. A slight change in the sprinkler spray pattern may have caused a failure in the 3.6 m and 4 m wide window tests. Since the sprinkler spray pattern may change due to many factors, such as sprinkler orientation, the use of a single sprinkler to protect a 3.6 m or wider window is not recommended for practical applications.

Mullion with depths of 25 mm or more affected the water spray to the opposite side of the mullion and a single sprinkler will not provide adequate protection for such a glazing assembly. For window systems with Mullions, multi-sprinkler protection should be considered.

When a multi-sprinkler system is used to protect a wide window or a window with a deep mullion, the sprinkler activation time for the second sprinkler may be adversely affected by the adjacent operating sprinkler. A series of tests, which was conducted to study the interaction between two
sprinklers, indicated that the interaction of adjacent sprinklers for wide windows protected by multi-sprinklers located 2 m apart at the top, does not, for the most part, interfere with the protection of the window systems. When there is a centre mullion (of at least 5 cm depth) between the sprinklers, the influence of water spray from the adjacent sprinkler was not significant and the second sprinklers activated in less than 40 s. For very wide windows without a mullion, the activation times of the second sprinkler, when located 2 m from an operating sprinkler, were in the range of 5 to 7 min. In the given test configuration, with one sprinkler operating at a pressure of 145 kPa, the critical conditions on the adjacent glazing surface were not reached until 10-11 min. Based on the test results, it is anticipated that the action of a sprinkler would not interfere with the performance of an adjacent sprinkler. Therefore, a wide window system or a window with mullions can be protected by a multi-sprinkler system, without the concern of sprinkler activation delay when sprinklers are at least 2 m apart. Since the activation time of a second sprinkler could change significantly depending on many factors, such as first sprinkler pressure and spacing, these test results should not be extrapolated to other window conditions. The second sprinkler activation time would also change drastically if there were changes in the sprinkler orientation or location.

The use of ceiling-mounted sprinklers to protect glazing assemblies is gaining interest from building designers. A study to determine the effectiveness of such a system showed two areas of concern; sprinkler activation time and water spray pattern onto the glazing surface. Ceiling-mounted sprinklers, both standard and fast response, have been shown not to activate in time to protect tempered glazing from a small fire located adjacent to the glass. This limits the use of ceiling-mounted sprinklers in protecting glazing assemblies. Ceiling-mounted sprinklers can, however, be used to protect a glazing assembly in those cases where the base of the glazing is at least 1 m above the floor. In such instances, the chances of having a small localized fire impinging on the glazing are small, and thus the system would not be expected to face this challenge.

The sprinkler water spray onto the glazing surface depends on three configuration parameters; window sill depth, sprinkler height, and sprinkler distance. The results of a series of sprinkler spray pattern tests indicated that the chance of glass breakage from fire exposure increases generally with an increase in sill depth, an increase in sprinkler height and an increase in sprinkler distance. This is based on the size of the dry area for each configuration, because, as the dry area increases, there is an increased probability of glass breakage from thermal stress. Among the window configurations tested, a window configuration of 15 cm sill depth, 45 cm sprinkler height and 60 cm sprinkler distance was considered to be the practically-worst case.

Fire tests of ceiling-mounted sprinkler protection for a 1.8 m wide tempered glazing system with a practically-worst case configuration showed that the sprinkler water spray protection was good enough to provide 1 hr fire protection on the glazing system. When a ceiling-mounted fast response sprinkler is located at an ideal position (0.3 m away from the glazing surface and 0.3 m above the top of the window with minimum window sill depth), the sprinkler water spray would provide sufficient fire protection for a tempered glass window a with maximum width of up to 2.6 m for at least 1 hr. To protect a wide window, a multi-sprinkler system could be used. In a ceiling-mounted configuration (1.8 m apart), the sprinkler activation delay due to adjacent sprinkler operation is not a problem.

CONCLUSIONS

A facility and test procedure have been developed for evaluating sprinkler protection of large glazing assemblies. In this paper, the maximum width of a window which can be protected by a single sprinkler and multiple sprinklers, as well as the ability of a ceiling-mounted sprinkler to protect a large glazing assembly were investigated. From these series of experiments, the following conclusions were drawn.

1) A tempered glass window, up to 2.6 m wide, can be protected from fire exposure with a single dedicated window sprinkler located at the top centre, for up to 2 hrs with a minimum sprinkler pressure of 175 kPa.

2) If there is a centre mullion with a depth of 25 mm or more, the water spray to the other side of the mullion will be adversely affected, and a single sprinkler will not provide adequate
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protection to the glazing assembly. For window system with mullions, multi-sprinkler protection should be considered.

3) In multi-sprinkler protection for wide windows, the interaction of adjacent fast response sprinklers located at the top, 2 m apart, does not interfere with the protection of the window systems, in most cases. If the distance between the fast response sprinklers is less than 2 m, the use of a window mullion (of at least 5 cm depth) between the sprinklers will prevent cold soldering of the sprinklers.

4) Ceiling mounted sprinklers located up to 0.6 m from the glazing will provide at least 1 hr of fire protection for a 1.8 m wide tempered glazing system with a maximum of 15 cm sill depth.

5) If the window sill depth is less than 10 cm and a ceiling-mounted sprinkler is located 0.3 m away from the glazing and 0.3 m above the top of the window, the sprinkler provides protection for a tempered glass window, with maximum width of up to 2.6 m, for at least 1 hr.

6) When multiple sprinklers are used in a ceiling-mounted configuration (1.8 m apart) to protect a multi-window system, sprinkler activation delay due to adjacent sprinkler operation is not a problem.

REFERENCES


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### TABLE 1

**Maximum Coverage by Single Sprinkler Test Results**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Window Assembly</th>
<th>Sprinkler Location</th>
<th>Glass Type</th>
<th>Effective Window Size</th>
<th>Water Pressure</th>
<th>Failure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6 m wide 1.5 m high</td>
<td>Top centre</td>
<td>Tempered</td>
<td>2.6 m wide 1.5 m high</td>
<td>172 kPa</td>
<td>No failure for 120 min</td>
</tr>
<tr>
<td>2</td>
<td>2 panses of 0.9 m wide glazing with butt joint</td>
<td>Top corner</td>
<td>Tempered</td>
<td>2.6 m wide 1.44 m high</td>
<td>145 kPa</td>
<td>No failure for 60 min</td>
</tr>
<tr>
<td>3</td>
<td>2 panses of 0.9 m wide glazing with 10 mm mullion</td>
<td>Top corner</td>
<td>Tempered</td>
<td>3.6 m wide 1.44 m high</td>
<td>145 kPa</td>
<td>No failure for 60 min</td>
</tr>
<tr>
<td>4</td>
<td>2 panses of 0.9 m wide glazing with 25 mm mullion</td>
<td>Top corner</td>
<td>Tempered</td>
<td>3.6 m wide 1.44 m high</td>
<td>145 kPa</td>
<td>23 min</td>
</tr>
<tr>
<td>5</td>
<td>3.0 m wide 0.7 m high</td>
<td>Top, 2 m left of right corner</td>
<td>Tempered</td>
<td>4.0 m wide 0.7 m high</td>
<td>145 kPa</td>
<td>No failure for 60 min</td>
</tr>
<tr>
<td>6</td>
<td>3.0 m wide 0.7 m high</td>
<td>Top right corner</td>
<td>Tempered</td>
<td>5.0 m wide 0.7 m high</td>
<td>145 kPa</td>
<td>15 min</td>
</tr>
</tbody>
</table>

### TABLE 2

**Test Results of Multi-Sprinkler Activation Times**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Window Assembly</th>
<th>Sprinkler Location</th>
<th>Glass Type</th>
<th>Mullion Depth</th>
<th>Water Pressure</th>
<th>2nd Sprinkler Activation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>No mullion</td>
<td>172 kPa</td>
<td>17 s</td>
</tr>
<tr>
<td>2</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>No mullion</td>
<td>345 kPa</td>
<td>No activation</td>
</tr>
<tr>
<td>3</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>No mullion</td>
<td>345 kPa</td>
<td>25 min 38 s</td>
</tr>
<tr>
<td>4</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>5 cm</td>
<td>172 kPa</td>
<td>17 s</td>
</tr>
<tr>
<td>5</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>5 cm</td>
<td>345 kPa</td>
<td>34 s</td>
</tr>
<tr>
<td>6</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>10 cm</td>
<td>172 kPa</td>
<td>20 s</td>
</tr>
<tr>
<td>7</td>
<td>2.6 m wide</td>
<td>Top, 1.8 m apart</td>
<td>Tempered</td>
<td>10 cm</td>
<td>345 kPa</td>
<td>26 s</td>
</tr>
<tr>
<td>8</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>No mullion</td>
<td>172 kPa</td>
<td>7 min 3 s</td>
</tr>
<tr>
<td>9</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>No mullion</td>
<td>345 kPa</td>
<td>No activation</td>
</tr>
<tr>
<td>10</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>5 cm</td>
<td>172 kPa</td>
<td>37 s</td>
</tr>
<tr>
<td>11</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>5 cm</td>
<td>345 kPa</td>
<td>37 s</td>
</tr>
<tr>
<td>12</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>10 cm</td>
<td>172 kPa</td>
<td>27 s</td>
</tr>
<tr>
<td>13</td>
<td>2.6 m wide</td>
<td>Top, 1.5 m apart</td>
<td>Tempered</td>
<td>10 cm</td>
<td>345 kPa</td>
<td>31 s</td>
</tr>
</tbody>
</table>
### TABLE 3
Test Results of Multi-Sprinkler Window Protection

<table>
<thead>
<tr>
<th>Test #</th>
<th>Effective Window Size</th>
<th>Joint Type</th>
<th>Sprinkler Type and Location</th>
<th>Water Pressure</th>
<th>Sprinkler Activation Time</th>
<th>Failure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 m wide 1.5 m high</td>
<td>Butt-joint</td>
<td>Standard 2 m apart</td>
<td>145 kPa</td>
<td>12 min 50 s</td>
<td>12 min 50 s</td>
</tr>
<tr>
<td>2</td>
<td>4 m wide 1.5 m high</td>
<td>Butt-joint</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>5 min 41 s</td>
<td>No failure</td>
</tr>
<tr>
<td>3</td>
<td>4 m wide 1.5 m high</td>
<td>2.5 cm mullion</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>6 min 30 s</td>
<td>No failure</td>
</tr>
<tr>
<td>4</td>
<td>4 m wide 1.5 m high</td>
<td>2.5 cm mullion</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>8 min</td>
<td>No failure</td>
</tr>
<tr>
<td>5</td>
<td>4 m wide 1.5 m high</td>
<td>2.5 cm mullion</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>9 min</td>
<td>No failure</td>
</tr>
<tr>
<td>6</td>
<td>4 m wide 1.5 m high</td>
<td>2.5 cm mullion</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>10 min</td>
<td>No failure</td>
</tr>
<tr>
<td>7</td>
<td>4 m wide 1.5 m high</td>
<td>No joint</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>8 min</td>
<td>No failure</td>
</tr>
<tr>
<td>8</td>
<td>4 m wide 1.5 m high</td>
<td>No joint</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>9 min</td>
<td>No failure</td>
</tr>
<tr>
<td>9</td>
<td>4 m wide 1.5 m high</td>
<td>No joint</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>10 min</td>
<td>No failure</td>
</tr>
<tr>
<td>10</td>
<td>4 m wide 1.5 m high</td>
<td>No joint</td>
<td>Fast Response 2 m apart</td>
<td>145 kPa</td>
<td>11 min</td>
<td>No failure</td>
</tr>
</tbody>
</table>

* The second sprinkler was activated manually. The temperature history of the second sprinkler showed that the second sprinkler would have activated between 5 and 7 min into the test.

### TABLE 4
Test Results of Ceiling Mounted Sprinkler Activation Times

<table>
<thead>
<tr>
<th>Test #</th>
<th>Window Assembly</th>
<th>Sprinkler Location</th>
<th>Sprinkler Type</th>
<th>Water Pressure</th>
<th>2nd Sprinkler Activation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6 m wide 1.5 m high</td>
<td>1.8 m apart</td>
<td>Fast response Pendant</td>
<td>152 kPa</td>
<td>15 s</td>
</tr>
<tr>
<td>2</td>
<td>2.6 m wide 1.5 m high</td>
<td>1.8 m apart</td>
<td>Fast response Pendant</td>
<td>193 kPa</td>
<td>17 s</td>
</tr>
<tr>
<td>3</td>
<td>2.6 m wide 1.5 m high</td>
<td>1.8 m apart</td>
<td>Fast response Pendant</td>
<td>345 kPa</td>
<td>22 s</td>
</tr>
<tr>
<td>4</td>
<td>2.6 m wide 1.5 m high</td>
<td>1.8 m apart</td>
<td>Fast response Pendant</td>
<td>517 kPa</td>
<td>24 s</td>
</tr>
</tbody>
</table>