

THE PROTECTION OF GLAZING SYSTEMS WITH DEDICATED SPRINKLERS

by

A.K. Kim and G.D. Lougheed
National Research Council of Canada
Institute for Research in Construction

SUMMARY

Water spray is one method of protecting glazing exposed to fire. Research conducted at the National Research Council's National Fire Laboratory indicates that, under ideal conditions, a window assembly, when protected by special sprinklers, will stay intact, and can obtain a fire resistance rating of 2 hours or longer. Experiments showed that there are several parameters related to sprinkler operation which affect the performance of the glazing assembly under fire exposure. This paper describes the test facility and discusses the results of investigations conducted to determine the effect of the sprinkler activation time and sprinkler water flow rate on the effectiveness of dedicated sprinkler systems for protecting large glazing assemblies. The effect of the sprinklers on the average temperature and temperature gradient in the test room is also discussed.

INTRODUCTION

There is an increasing demand to use glazing assemblies in fire separations or in the exterior envelope of a building for aesthetic, security and economic reasons. However, ordinary glass will shatter due to thermal stresses after only a few minutes exposure to fire. With external glazing, this could allow the fire to spread to other floors or to adjacent structures and, with interior glazing, there is increased risk of fire and smoke spread to other parts of the building. Building codes, including the National Building Code of Canada (NBCC)¹, have, therefore, strictly regulated the use of glazing in fire-rated assemblies.

Traditional methods for achieving fire resistant construction with glazing require the use of small panes with wire reinforcement. In recent years, fire performance tests with borosilicate glazing have shown that glazing integrity can be maintained for up to 125 min, depending on the glazing size and the frame material². There are, however, economic and aesthetic problems with these solutions. An alternative solution is to use automatic sprinklers to protect the glazing. Although water spray is an established method for controlling fire spread, there is lim-

ited experimental evidence to justify the use of sprinklers to protect glazing in fire-rated separations.

The prior publication³ on the protection of glazing assemblies using sprinklers showed that protection can be provided for specific window assemblies. However, the effect of various sprinkler parameters were not investigated. This paper presents more detailed information on the sprinkler protection system and also answers some of the questions regarding the test methodology and the effect of various parameters which arose from the previous investigations.

Under fire conditions, the protection afforded glazing systems by automatic sprinklers depends on several factors. The two primary factors are the ability of the sprinkler to operate before critical stresses are formed in the glazing and, having fused, the ability of the sprinkler to keep the glazing and the frame cool throughout the fire. These factors are discussed in this paper. A series of tests was also conducted to determine the effect of water flow rate on the temperature gradient and average temperature in the fire compartment. In this paper, the results of the investigations on sprinkler activa-

tion times and water flow rate are discussed. These studies along with ongoing investigations regarding sprinkler interaction and other problems will form the basis for developing a general design guide for the method. In addition to the experimental data, this paper will also describe the test facility which has been used at the the National Research Council of Canada's National Fire Laboratory (NRCC/NFL) to investigate these special sprinkler systems for protecting large window assemblies.

PREVIOUS WORK

A limited number of investigations have been carried out to test the concept of water spray on glazing as a method of protecting a window assembly. Notably, Underwriters Laboratories Inc.⁴ in United States, Moulen and Grubits^{5,6} in Australia and the Greater London Council Safety Branch^{7,8} in the United Kingdom, conducted full-scale tests using large panes of glass protected by water spray. These studies showed that glass panes which were continuously wetted with water did not fracture when exposed to high levels of radiation or to flame from a burner. However, these investigations were confined to a case by case study and did not carefully investigate the various parameters involved in the total performance of the glazing assemblies.

To study whether fires directly adjacent to tempered glass could produce high stresses in the glass before the activation of the sprinkler, Beason⁹ carried out some tests using 1.73 m (68 in.) x 2.44 m (96 in.) tempered, plate and laminated glass. Two fire sizes were used: a pool fire of about 250 kW and a 40 kW natural gas diffusion flame. Two standard 71°C (160°F) automatic sprinklers were installed at the 2.44 m (8 ft) high ceiling, 1.8 m (6 ft) apart and both 0.3 m (1 ft) away from the glazing. The tests showed that with a large fire, the temperature rise in the room was sufficiently fast to fuse the sprinklers before excessive stresses were produced in tempered glass. However, a small fire, directly adjacent to the glass surface produced sufficient localized stress to shatter the glass before the sprinklers activated. Plate and laminated glass when exposed to large fires cracked before the sprinklers fused. However, both remained in their frames following sprinkler operation.

Earlier work done at NRCC indicated that when protected by continuous water film, a glazing assembly can withstand fire exposure for more than 2 hrs.^{3,10} Without water protection, tempered glass failed within 7 min when exposed to fire. When water was sprayed onto the hot glazing, however, the glazing failed much earlier (approximately 4 min). These investigations did indicate that a glazing system exposed to fire can be protected if sufficient water is sprayed in time and forms a continuous film. This paper gives the results of further investigations conducted to determine the effects of water flow rate and sprinkler activation time on the effectiveness of the dedicated sprinkler protection system.

TEST FACILITY

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 (Figure 1). The walls were constructed of concrete blocks protected on the inside with 25 mm thick ceramic fibre insulation. The ceiling was constructed with mineral fibre tiles supported by a grid formed with steel studs. The grid was supported by 38 mm x 140 mm steel joists. The ceiling assembly was protected on the underside by 25 mm thick ceramic fibre insulation.

The window assemblies were mounted in the east wall of the burn room and were installed in a steel stud wall protected with a double layer of 13 mm thick gypsum board to fill the space between the window frame and the concrete block wall (Figure 1). A 25 mm space below the

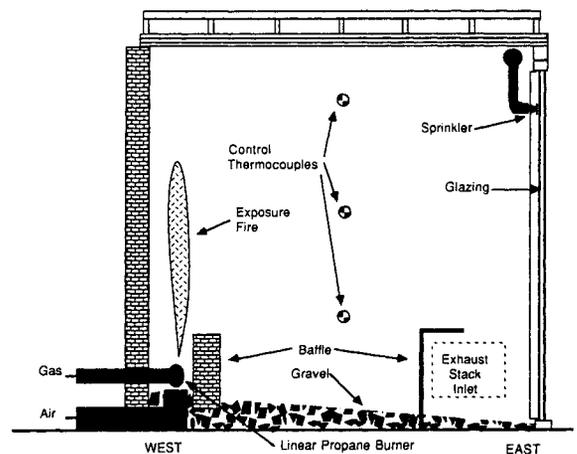


Figure 1 Section of test room.

window assembly at floor level allowed surplus water to drain from the room.

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-section 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.

Glass temperatures were measured at several locations on both the exposed and unexposed side of the assembly using 30-gauge chromel-alumel thermocouples bonded to the glass with clear epoxy resin. Previous studies investigated the effect of thermal radiation on the glass temperature measurement. In these tests, thermocouples were bonded to the glass surface with clear epoxy and with opaque white epoxy. Also, some thermocouple beads were protected using thin adhesive foils. The results showed there was minimal difference in the glass temperature measured with the covered and uncovered thermocouples or with the opaque and clear epoxy. Since the measured glass surface temperature was not significantly effected by thermal radiation to the thermocouple beads, the clear epoxy was used to bond the thermocouple beads to the glass surface in all subsequent tests.

SPRINKLER ACTIVATION STUDY

To determine the temperature range at which

glass breaks with and without the thermal shock of a water spray, a series of tests was conducted with a small-scale test facility. This apparatus was used previously by McGuire¹¹ for his investigations. In these tests, 0.3 m x 0.3 m glass panes were held by a simple frame and were exposed to different levels of radiation (up to 43 kW/m²). A total of 19 tests were conducted examining plain, heat strengthened and tempered glass. When exposed to high radiation, the plain glass broke within a few minutes with a temperature on the exposed side of 150-175°C. Tempered and heat strengthened glass did not break even when the maximum temperature reached 350°C. A summary of the test results are given in Table 1.

In the second phase of the small-scale tests, glass samples were heated for various durations by high intensity radiation (up to 43 kW/m²). Water was then sprayed manually on the exposed side of the hot glass to measure the maximum temperature at which the glass could withstand the impact of sudden cooling by water spray without breaking. A total of 50 tests were conducted on the three types of glass. A summary of the test results is given in Table 2. The tempered glass, which under dry conditions did not break even when exposed to the maximum radiation level of 43 kW/m² for 20 min, shattered when water was sprayed on it. The maximum exposed side glass temperature reached 200°C before breakage. The range of exposed side temperatures for plain and heat strengthened glass to withstand the impact of water spray was 80-90°C and 150-165°C, respectively.

A series of tests was conducted using the full-

Table 1. Small-scale test results.

Glass Type	Radiation Exposure (kW/m ²)	Failure Time (min)	Temperatures	
			Exposed Side (°C)	Unexposed Side (°C)
Plain	10	< 8	160	140
Plain	40	< 1	150 - 175	75 - 150
Heat Strengthened	43	No failure	350	300
Tempered	43	No failure	350	300

Table 2. Small-scale test results with water spray applied to the fire exposed side.

Glass Type	Maximum Temperature to Withstand Water Spray	
	Exposed Side (°C)	Unexposed Side (°C)
Plain	80 - 90	70
Heat Strengthened	150 - 165	130 - 150
Tempered	200	170

scale test facility to determine sprinkler activation times for various locations in the burn room. In these tests, two different types of sprinklers (standard with a temperature rating of 74°C and an *RTI* of 127 m^{1/2}s^{1/2} (230 ft^{1/2}s^{1/2}), and fast response with temperature rating of 74°C and an *RTI* of 22.7 m^{1/2}s^{1/2} (41 ft^{1/2}s^{1/2})) were installed at various locations on the ceiling and near the top of the window frame. The sprinkler activation times and the glazing temperature history were monitored for a fire exposure provided by either the linear burner at the back wall or by a small 300 mm x 300 mm sand burner located adjacent to the glazing.

The glazing, when exposed to a 730 kW fire provided by the linear burner, reached a temperature of 80°C at 45 s, 160°C at 150 s and 200°C at 220 s. Standard sprinklers activated within 90 s and fast response sprinklers activated within 30 s. Based on the glass breaking temperature information obtained in the small-scale tests, all sprinklers would activate before reaching the critical temperature due to thermal shock for the tempered and heat strengthened glazing. Only the fast response sprinklers would activate prior to a plain glazing reaching the critical temperature. It was found that when exposed to a large fire located away from the glazing, the glazing temperature increases gradually while the gas temperature at or near the ceiling rises substantially. Therefore, sprinklers would activate well before any critical stresses are formed in the glazing.

In 1986, Beason⁹ published the results of tests on a sprinklered glass wall using a slowly developing fire located close to the glazing. These test showed that the glazing failed before the sprinklers acti-

vated. Similar tests were conducted at NRCC to study the effect of such fires on the sprinkler activation time. With a slowly developing fire located near the glazing, the temperature on the glazing increased rapidly. However, the fire was not sufficiently large to produce a rapid increase in air temperature near the ceiling and corresponding early sprinkler activation. This is thus the worst case situation for the protection of glazing assemblies with sprinklers.

The NRCC tests showed that heat strengthened and tempered glass systems can be adequately protected from a slowly developing fire which is located near the glazing, by using fast response sprinklers located close to the glazing. Standard sprinklers would not activate before the tempered or semi-tempered glazing breaks. Even fast response sprinklers located away from the glazing (such as the 300 mm described in NFPA 101, Life Safety Code¹²) would not activate early enough to prevent the glazing from breaking due to thermal shock.

This study shows the importance of the sprinkler activation time in the protection of glazing assemblies. In a normal situation, the fire exposure in the room will be large and located some distance away from the glazing. In this case, both standard and fast response sprinklers would activate before the critical temperatures for semi-tempered and tempered glass are reached. However, for the worst case situation with a small fire such as a waste basket fire located close to the glazing with impinging flames, local glazing temperature will rise very rapidly. In this case, only fast response sprinklers located close to the glazing will activate early enough to protect semi-tempered and tempered glazing.

WATER FLOW RATE STUDY

Full-scale Test Procedure

For the earlier tests with automatic sprinkler protection for glazing described in Reference 3, the propane and air flow were controlled to maintain the average room temperature as close as possible to the standard time-temperature curve with sprinklers operating. This produced a more severe fire exposure to the window assembly than would occur in an actual fire scenario as the sprinklers would not only protect the window but would also affect local room conditions. With the present test arrangement, a predetermined fire load was used. 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-20 gauge thermocouples enclosed in 6 mm diameter Inconel sheaths to minimize the influence of water spray. The thermocouple beads were positioned 1/3 the room width from the walls and in the midplane between the test assembly and the burner. The thermocouples were located 600 mm below the ceiling, 600 mm above the floor and at midheight. The gas flow and corresponding temperature curve are shown in Figure 2. The precalibrated 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.

Some problems in maintaining the fire were encountered in early tests. Under standard conditions, the lower and upper flammability limits for a propane/air mixture is 2.1% and 9.5% concentration by volume of propane, respectively. However, water vapour can substantially decrease the flammability range, or with higher concentrations, produce a nonflammable mixture¹³.

A Beckman Hydrocarbon Analyzer, precalibrated for propane, was used to investigate the effect of the increased water vapour accumulation in the room air on the propane fire. A continuous measurement was made of the propane concentration in the exhaust gas. The hydrocar-

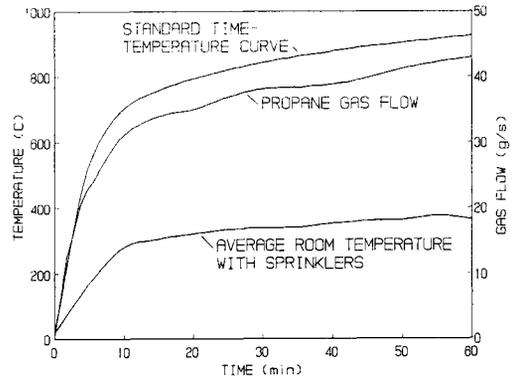


Figure 2 The standard time-temperature curve, propane gas flow and average room temperature with 180 L/min water flow rate.

bon measurement shown in Figure 3 indicates that there was no significant change in propane concentration in the exhaust gas for the first 37 min of the test. The rapid increase in the propane level coincided with a visible decrease in flame intensity and eventual extinguishment of the propane fire.

The test room was subsequently modified to minimize water vapour in the burner combustion zone. These modifications included the installation of a metal baffle extending the full width of the burn room and located between the exhaust ducts and the burner. The height of the brick baffle in front of the burner was increased to 1.2 m. An additional 700 CFM of air was supplied to the propane burner to ensure efficient propane combustion. With the modified facility, tests of up to 2 hr in duration were run without any extinguishment problems. The hydrocarbon level in the exhaust stack was less than 0.05% throughout the test with the modified room indicating that the combustion efficiency was

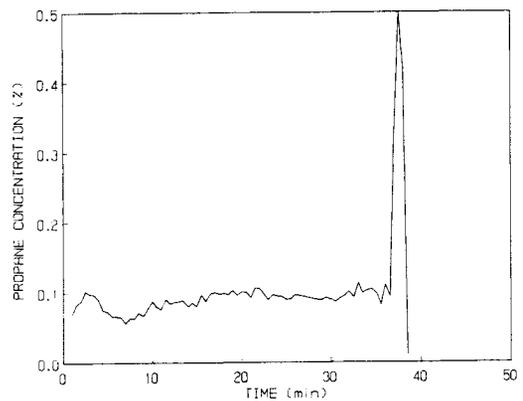


Figure 3 Propane concentration in exhaust duct.

not significantly effected by the water vapour accumulation in the room. It was determined, therefore, that the total heat release in the test room was not decreased by the action of the water spray, and that the window assembly with the water spray provided by the sprinklers was subjected to the same fire load as in the non-sprinklered calibration test.

In practice, the window sprinkler system would probably be used in conjunction with a room sprinkler system. That system would suppress the room fire and further decrease the fire effects on the window assembly. It was concluded, therefore, that the present tests subjected the sprinkler protected window assemblies to the same fire load which, under non-sprinklered conditions, would produce the standard time-temperature, and that these tests should be a conservative representation of the fire effects on the test assembly in normal applications of the technology.

Window Assemblies

Three different window assemblies with sprinkler protection were tested for use in an exterior

building envelope. All window assemblies were double glazed using 6 mm thick glass. A brief description of the assemblies is given in Table 3. All assemblies were able to withstand the fire exposure, with sprinkler protection, without damage to the frame or glazing.

Sprinklers

Grinnell Model FR-1/Q-60 fast response sprinklers were installed at the centre of each window section. The centre line of the sprinkler deflectors was typically 50 mm below the top frame and 12 mm from the glass (Figure 4). The water flow rate was adjusted by a control valve on the sprinkler piping outside the burn room. Both the riser and the branch line mounted above the window assembly were 38 mm i.d. steel pipe to the first sprinkler. For the tests with two sprinklers, 32 mm i.d. steel pipe was used after the first sprinkler. The sprinklers were mounted horizontally as shown in Figure 4.

Water Flow Results

The sprinklers used in these tests were posi-

Table 3. Window assemblies.

Window Assembly	Description	Frame Dimensions		Individual Glass Pane Dimensions	
		Width (m)	Height (m)	Width (m)	Height (m)
1	two sealed double-glazed windows with tempered glass inner pane, heat strengthened outer pane and a centre mullion	3.08	3.21	1.27	2.67
2	a single sealed double-glazed window with heat strengthened glass inner and outer panes	2.25	3.00	2.10	2.82
3	two sealed double-glazed windows with heat strengthened glass inner and outer panes and a centre mullion	2.25	3.00	1.04	2.82

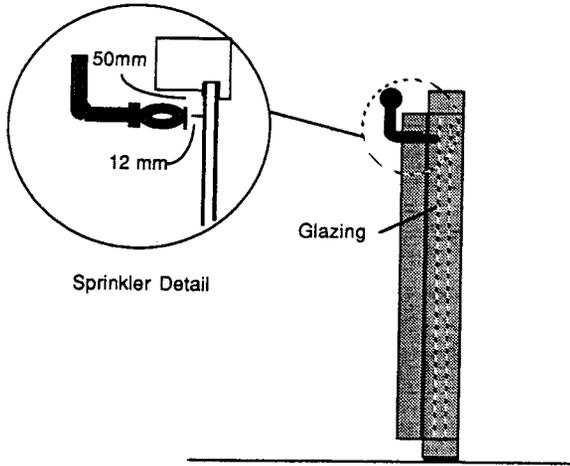


Figure 4 Sprinkler location.

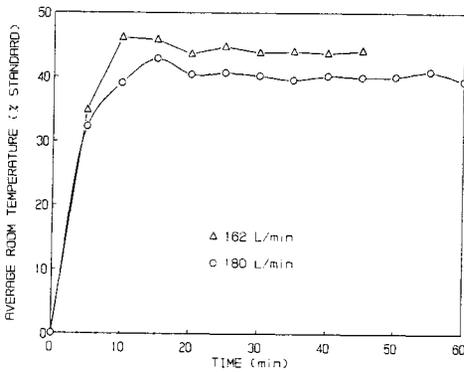


Figure 5 Average room temperature relative to the standard time-temperature curve.

tioned such that the water spray was directed primarily onto the glazing and the frame. Baffles were mounted on the room side behind the sprinklers to minimize back spray into the room. The water spray onto the glazing assembly did, however, have a substantial effect on the average room temperature and temperature gradient in the room.

Figure 5 shows the average room temperature with sprinklers operating, as a percentage of the standard time-temperature curve without sprinklers operating. After 20 min, virtually steady state conditions were achieved with the average room temperature a constant percentage of the temperature under non-sprinklered conditions. For these tests, the propane flow was continuously adjusted to follow the calibration curve shown in Figure 2.

A series of tests was conducted to determine the effect of sprinkler flow rate on the room conditions. For these tests, the propane flow to the burner was maintained constant at the level which would produce a room temperature corresponding to the 40 min point on the standard time-temperature curve (878°C) under non-sprinklered conditions.

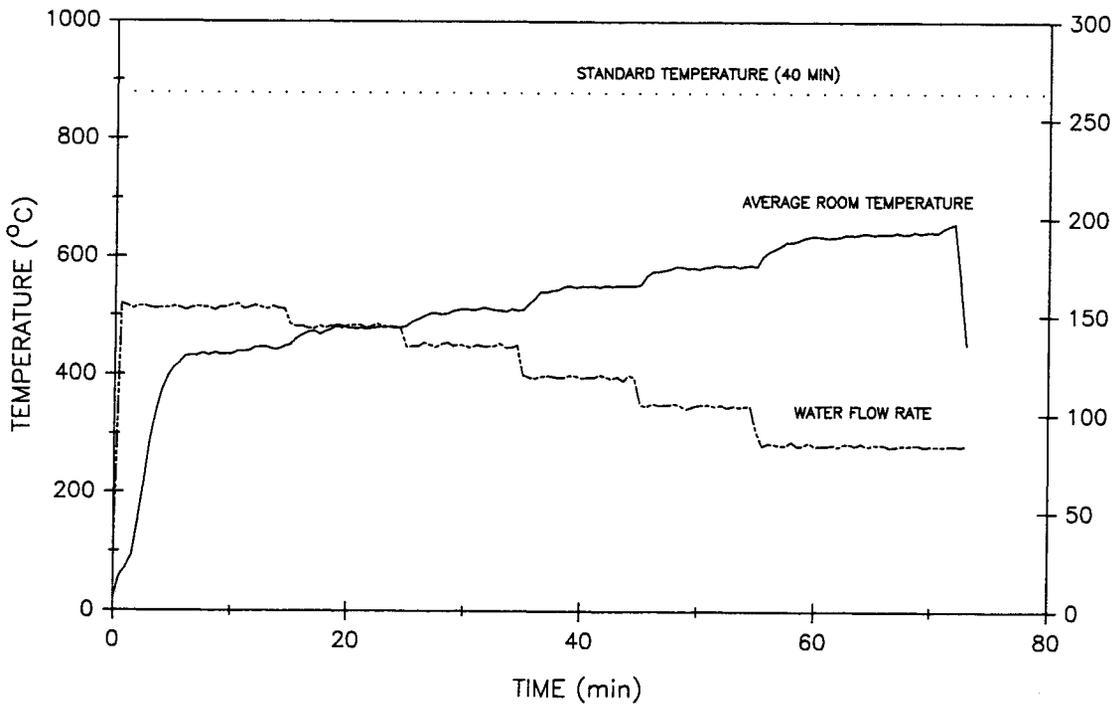


Figure 6 Average room temperature with decreasing water flow rate.

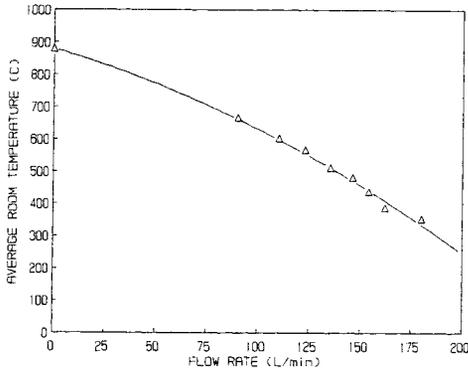


Figure 7 Average room temperature versus water flow rate.

In a test with Window Assembly 1, which was protected with two sprinklers, the water flow rate to the sprinklers was maintained constant at 150 L/min for the first 15 min, and was subsequently decreased in steps of 10 to 20 L/min at 10 min intervals. With each decrease in water flow rate, the average room temperature increased and stabilized at a higher steady state condition (Figure 6). The total water flow rate to the test room is also shown.

A plot of water flow rate versus average room temperature in the test room is given in Figure 7. A number of parameters, including the room dimensions, will affect the average room tem-

perature. For this series of tests, the variation in the average room temperature with water flow can be approximated by

$$T = T_0 - 1.8x - 0.007x^2$$

where T_0 is the temperature in °C for non-sprinklered conditions and x is the water flow rate in L/min. The variation in the average room temperature was nearly linear with the sprinkler flow rate. The predominant effect was due to the increased heat loss to the sprinkler water at higher flow rates.

In a subsequent test with Window Assembly 3, the room temperatures were measured with 7 thermocouples mounted at midheight and at the 1/8 points between the test assembly and the burner. At the 1/4 (.9 m) and 1/2 (1.8 m) points, 200 mm diameter pipes were used to shield the thermocouples from direct water spray. The thermocouples were mounted with the bead at the centre of the pipe and 25 mm from the open end. These thermocouples were thus protected from direct spray from the sprinklers. The room temperatures measured at several locations in the room are shown in Figure 8. (The thermocouple position is indicated relative to the

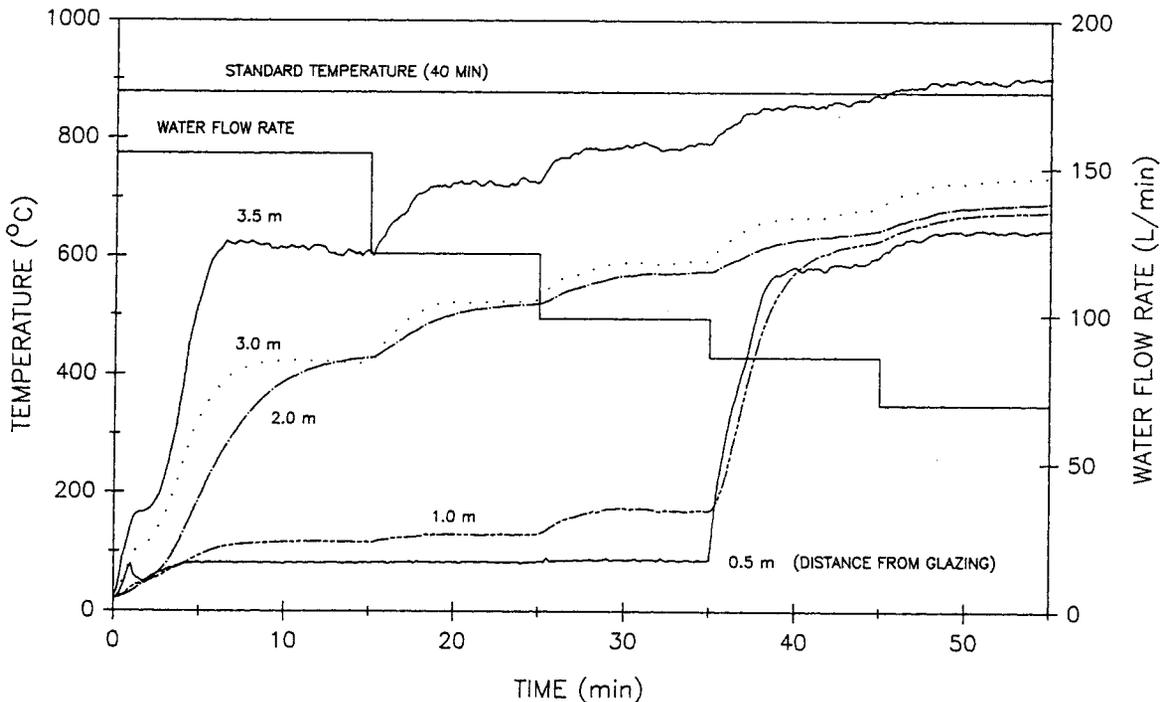


Figure 8 Midheight temperatures in the test room measured at specified distances from the glazing with decreasing sprinkler water flow rate.

window assembly.) The total water flow rate to the test room is also shown. This flow rate was decreased in steps at 10 min intervals. There was minimal temperature variation in the middle section of the room indicating there was good mixing of the room air. With the higher initial flow rates, room temperatures near the window assembly were relatively cold (100°C). The cooling in this region is most likely due to evaporation from the water film on the glazing and the formation of a misty region close to the glazing assembly. The water flow rate had to be substantially decreased before a rapid increase was noted in the temperature in this region (35 min). The temperature measured by the thermocouple closest to the burner was substantially higher than measured in other sections of the room, and, with lower flow rates, the temperature measured with this thermocouple approached the standard temperature.

At high sprinkler pressures, the window protection system was very effective in maintaining the window frame and glazing temperatures below 100°C. In Figure 9, the temperatures measured at two locations on the glass (upper corner and lower region) are shown as the total water flow rate to the test room with two active

sprinklers is decreased. As the sprinkler pressure was decreased, there was minimal variation in the glazing temperatures until dry areas developed. The most critical areas were the upper corners of the glazing, which were not well wetted with reduced flow rates (< 60 L/min to each sprinkler). The temperature in the dry area in the upper corner of the glazing reached 350-400°C before the tempered glazing broke from thermal stresses. The temperatures measured in other regions of the glazing were considerably lower with a peak temperature of 200°C measured in the lower section of the glazing.

The total heat flux to the window assembly was also measured in the test with Window Assembly 3. The propane flow to the burner was constant and the sprinkler water flow rate decreased in steps at 10 min intervals. A Medtherm 64 Series water-cooled heat flux meter was mounted through the centre mullion and at 2/3 the room height. The centre mullion was mounted on the fire exposed side of the glazing and extended 100 mm into the test room. The sprinkler spray was directed at the glazing surface, and thus did not significantly affect the heat flux measurement. The total

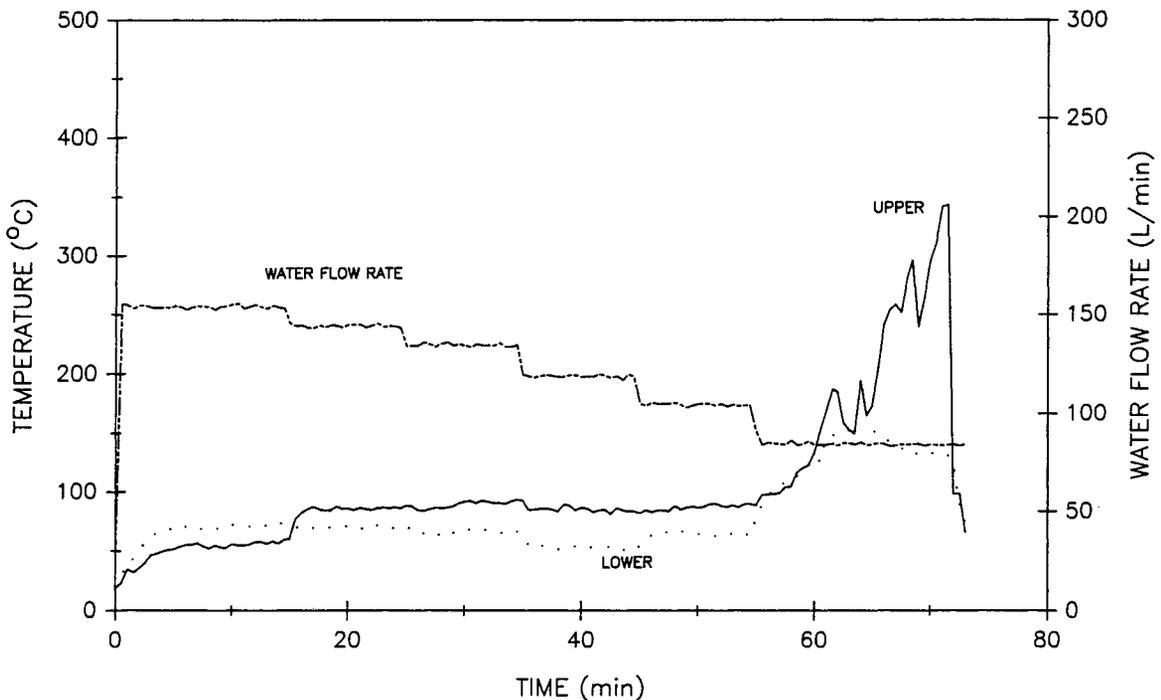


Figure 9 Glazing temperatures with decreasing sprinkler water flow rate.

heat flux to the glazing would be further decreased by the water film. With high sprinkler water flow rate, the total heat flux to the assembly was maintained below 25 kW/m², but reached 40-50 kW/m² with decreased water flow rates (Figure 10). The total water flow rate to the test room is also shown. Under non-sprinklered conditions, a total heat flux of 100 kW/m² was measured at the same location. Thus, the convective heat flux was reduced by the cooling of the air in the test room near the window assembly. Also, the radiant flux was attenuated by the water vapour in the air.

The radiation transmitted through the centre of the glazing was also measured. For these measurements, a radiometer was positioned 300 mm from the exterior glass pane. A peak transmission of 0.25 kW/m² was observed through the sprinkler protected glazing assembly. Under non-sprinklered conditions, the thermal radiation through a double pane of glazing was approximately 8 kW/m². Thus, the glazing alone absorbs more than 90% of the total thermal flux. The water vapour in the test facility and the water film on the glazing surface further attenuates the thermal radiation.

CONCLUSIONS

A facility and test procedure have been developed for testing sprinkler protection of large glazing assemblies. Under fire conditions, the protection afforded glazing systems protected by automatic sprinklers depends on several factors. In this paper, the ability of the sprinkler to operate before critical stresses are formed in the glazing and, once activated, to keep the glazing and the frame cool throughout the fire were investigated. Some of the findings are summarized as follows:

- 1) the impact of water spray on hot glazing can cause premature failure of the glass, and therefore early activation of sprinklers is essential,
- 2) the average room temperature was decreased by up to 60% with high sprinkler flow rates,
- 3) there was minimal variation in the room temperature in the central portion of the room with substantial cooling of the room only near the glazing assembly,
- 4) the water spray reduced the total heat flux density at the window assembly by 50-75% depending on the water flow rate,

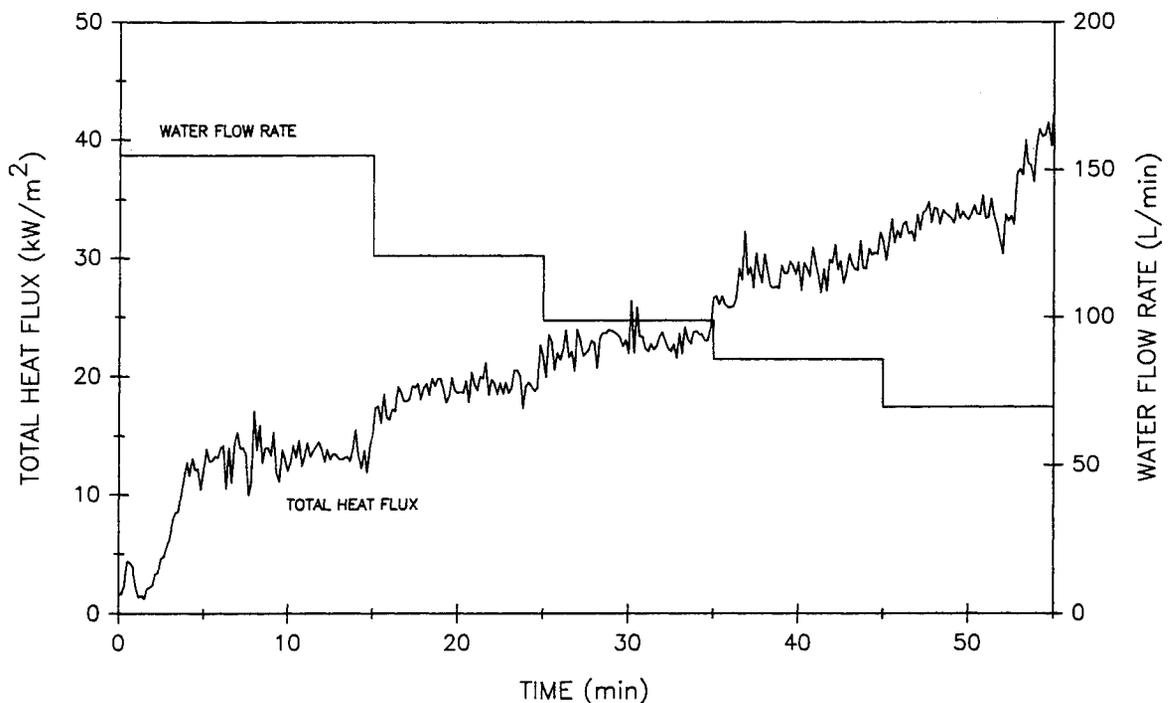


Figure 10 Total heat flux to the window assembly.

- 5) minimal radiant heat flux ($< 0.25 \text{ k/m}^2$) was measured on the unexposed side of the glazing.

The tests indicated that the worst case, in terms of sprinkler activation, is a small fire located close to glazing with impinging flames, such as a waste basket fire. In this case, standard sprinklers were not effective in protecting any type of glazing. Only fast response sprinklers located close to the glazing would activate early enough to protect semi-tempered and tempered glass.

The tests also indicated that the sprinklers did not affect the propane burner combustion efficiency, and thus the fire load to the test room was the same with sprinklers operating as with the initial calibration test. By using the propane flow rate which maintained the standard time-temperature curve under dry conditions, the window assembly including the sprinkler protection system was subjected to the same fire exposure.

All window assemblies were able to withstand the fire exposure for up to 2 hr with the higher water flow rates tested. With higher sprinkler water flow rates, the window assembly and the region of the room near the assembly remained relatively cold. The total heat flux to the glazing and the frame was substantially reduced. A substantial decrease in water flow rate was necessary before the glass would break in the tests with constant propane flow to the burner. With low sprinkler pressures, sufficient water was not delivered to the upper corners of the glazing, resulting in thermal stresses and eventual breakage.

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