Experimental Study on Gasoline Station Fire—Evaluation of Fire Safety

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ABSTRACT

Fire tests were carried out for full scale semi-enclosed gasoline station model. Two sizes of fire source, gasoline as a fuel, of 600 l in a 10 m^2 and 900 l in a 15 m^2 pool were used. The burning continued about 8 - 10 min. Three locations of fire pool inside model compartment, at the end corner, middle position, and foot of the opening, were chosen with respect to the tank truck area. The results show that burning rate of gasoline at the end corner and middle position in semi-enclosure indicated 4.9 - 5.8 mm/min, and is 20% - 40% high compared to free burning. Gasoline vapor slided out on the floor by strong convection, and which gave an apparent bigger size of burning area. As the pool at the foot of opening chosen, this phenomena was clearly observed, then flaming tornado was performed as high as 18 - 20m and its burning rate was about 7.4 mm/min. This may be due to vortex initiated natural wind. Wired window glasses on the scecond floor, sometimes were touched with flame, were not broken even exposed to the heat flux of 9 W/cm^2 instantaneously.

KEY WORDS : full scale model, gasoline station, pool fire, flaming tornado, flame length, wired glass, fire hazard

1. INTRODUCTION

Japanese Fire Code requires that a gasoline station must have at least two open sides which obtain access to roads. And some local fire departments have given strong recommendation that gasoline station should not be contained by multi- stories of tenant building and/or resident building. Therefor, almost gasoline service station locate at the corner of roads with single story structure. However, in large cities such as Tokyo area, price of land is surprisingly expensive and available areas are extremely limited. It have been pointed out both on the economical and effective land usage that the space above the gasoline station must be made the possible use as a multi-story building. As a gasoline station was not set at the corner of a building, it is expected that a gasoline station must have only one open side to access for visitors. If a fire occurred inside the service area of a gasoline station, it may produce a serious damage to the second and/or third floor(s). However, there are few clear and useful data which help

FIRE SAFETY SCIENCE—PROCEEDINGS OF THE SECOND INTERNATIONAL SYMPOSIUM, pp. 751-760

to make assessment the damages by gasoline fire.

In order to obtain the behavior of gasoline fire which occurred in semi-enclosed space such as a gasoline service station with one open side, the committee have been established and made a series of full scale experiments with the Center for Fire Science and Technology, Science University of Tokyo. The experiments composed from three parts; (1) Fire Behavior in Semi-enclosure with One Open Side, (2) Gasoline Vapor Diffusion Behavior, and (3) Evaluation of Fire Safety. First item of the experiment which contents reduced scale model tests and 10 full scale model tests have been carried out. The full scale experiments of the second item were carried out but the test data is still being analyzed, and the third item is still in the planning stage.

In this paper, as the first report of the experimental study, we will present mainly the fire behavior with regard to full scale test of the first item. Some tests were carried out with a water drencher system and having different length of pent roofs for fire protection. The primary objectives of the experiments is to obtain the fire behaviors under typical structural conditions of a gasoline station with one open side to help the assessment of fire safety for a gasoline station.

2. EXPERIMENTAL PROCEDURE

To obtain the basic fire behavior which occurred in a semi-enclosed space, a full scale model as shown in Figure 1-a was prepared. Figures 1-b and 1-c show the plan and the front elevation with the locations of instrumentation attached.

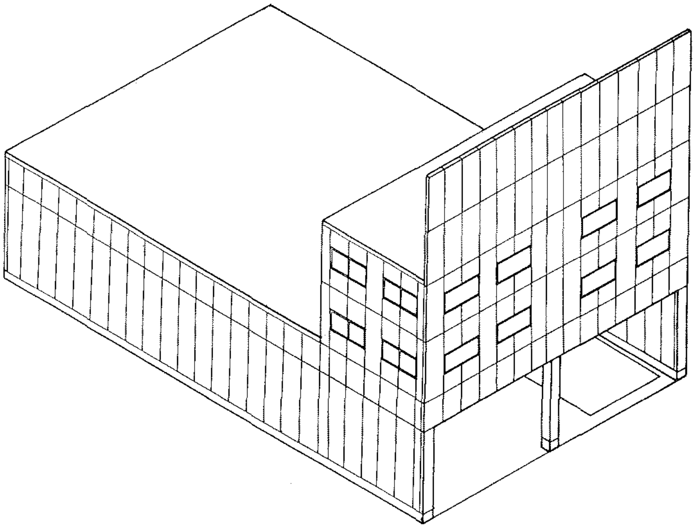

Figure 1-a. Full scale model of gasoline station

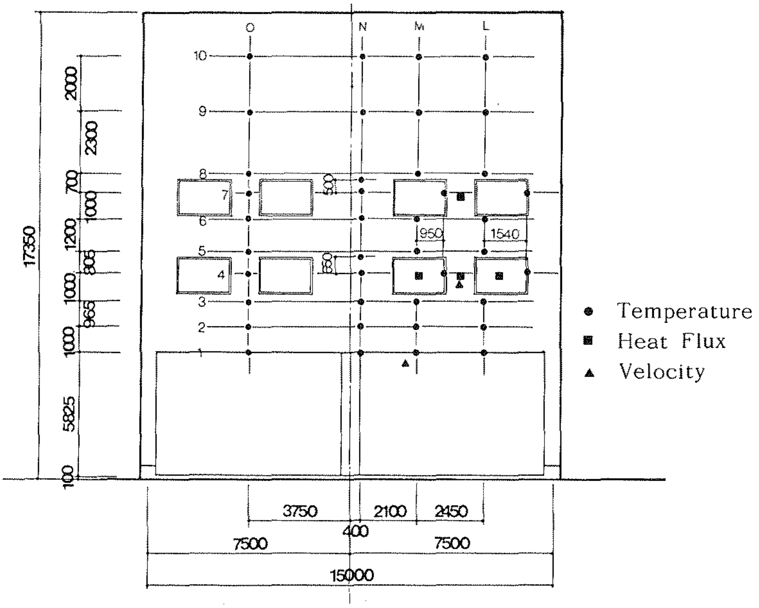

Figure 1-b. Front elevation of full scale model

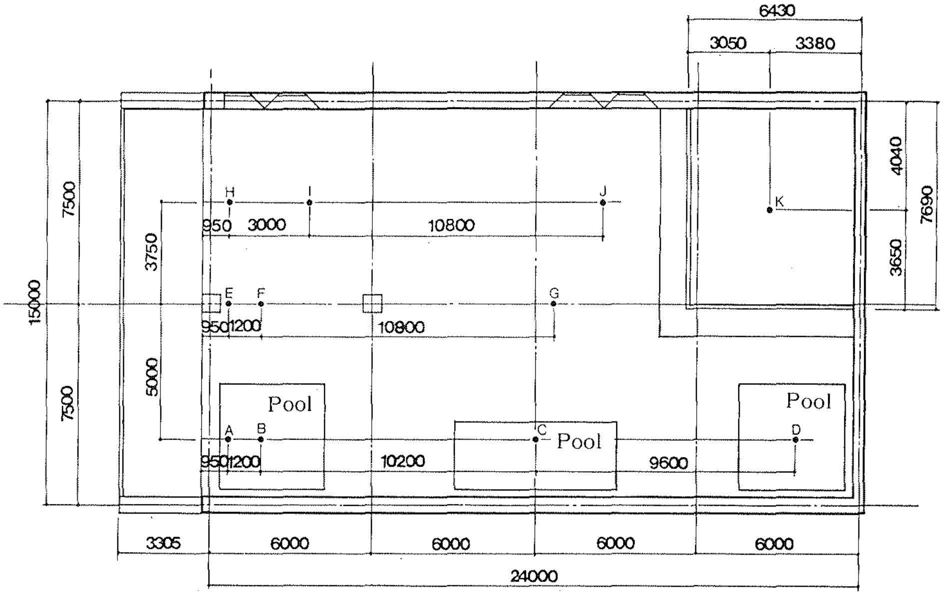

Figure 1-c. Plan of full scale model

The length of station model is 24m with 5m high ceiling and the opening width is 15m. It has partly three stories with extended wall which corresponds to two stories high. The structure of full scale model has steel frame sprayed with rock wool and cement. Ceiling was covered with ALC (Autoclaved Lightweigth Concrete) of 50mm thickness and inside wall with ALC panel of 100mm thickness. Exterior was covered with 120mm thickness PC (Precast Concrete) panel. Window sashes on the second and third floors are aluminum frame. Wired grass of 6.8mm thickness were set in the windows.

At the planning of a gasline station, the pool will be prepared as a collector of leaked gasoline to avoid the propagation on the gradient floor. The pool size is estimated based on the size of a gasoline tank-truck and service area. In the experiments, there are three pools of 15 m^2 area in the ground floor which locate at the end corner, middle position and at the foot of opening, respectively. In experiments of #1 - #3, 15 m^2 pool was reduced to 10 m^2 pool with ALC panels. Gasoline pool depth was about 30 cm, and of which 20 cm depth was filled with water prior to the each experiment. Table 1 shows the test condotions.

The first 7 experiments were conducted without fire protections. Passive fire protection system of a set of pent roof was employed in experiments of #8 and #9. In the experiment #10 an active protection of drencher system at the opening was adopted. The drencher system consisted of 6 heads at 2.5m spacing and was able to sprinkle water of 800 l/min as a total discharge rate.

The temperatures were measured at 100 points by means of 0.3mmϕ sheathed K-type thermocouples. They were set in the space of the service area, rooms on the second and third floors, and along the external wall. Radiative heat fluxes were measured at 7 points by means of radiometers with water cooling system. Bi-directional Pitot probe was set to measure the upward velocity along the wall of the second floor with about 10 cm apart from its surface and another probe was set under the ceiling at opening to measure the effluent flow velocity. The difference pressures were introduced by bi-directional probe with reference temperatures, and then velocities were estimated. The natural wind direction and velocity were also measured at the top of the full scale model. Output from these sensors were recorded every 10 seconds. The locations of measurement points are illustrated in Figures 1-a and 1-c.

Table 1 Conditions

Exp.	Location of pool	Gasoline	Area	Note
#1	at the end corner	600 L	10 sq.m	without protection
#2	middle position	600 L	10 sq.m	without protection
#3	at the foot of opening	600 L	10 sq.m	without protection
#4	at the end corner	900 L	15 sq.m	without protection
#5	middle position	900 L	15 sq.m	without protection
#6	at the foot of opening	900 L	15 sq.m	without protection
#7	middle position	900 L	15 sq.m	without protection
#8	at the foot of opening	900 L	15 sq.m	pent roof of 1.5 m
#9	at the foot of opening	900 L	15 sq.m	pent roof of 1.0 m
#10	at the foot of opening	900 L	15 sq.m	drencher of 800L/min

3. RESULTS AND DISCUSSION

3-1. Burning Rate Effected by Radiation and Wind

Gasoline pool was ignited electrically and ignition time was adopted as a start time. The full scale model was constructed in the open field of the university and experiments were carried out there. Some resident houses stands in almost south direction of the full scale model, therefore, we carried out the experiments in the wind direction of SSE - SSW to avoid the smoke attack to the houses. The opening of the full scale model faced to almost north. The natural wind passed away the full scale model from the behind and then hot smoky layer was disturbed by the wind. Consequently, there was no clear two layers. When natural wind condition was as mild as 1 - 2 m/sec, in experiments #4, two layers were clearly observed. In this case, the flame extended along the ceiling and facade as long as about 30 m from the fire origin. It was observed several times that the flame tip reached to the window glasses on the second floor. As the pool at the middle position and at the end corner were used, flame inclined toward end wall by convection flow generated by itself, as well as an apparent burning area spread out on the floor by the convection flow.

When the pool located at the foot of the opening was chosen as a burning area, in experiments #3, #6, #8, and #9, turbulent flame changed to flaming tornado within about 1 minute after the ignition. Tornado extended as high as about 20m with roaring. The diameter of the tornado was almost as same size as a pool width, but at the foot of the tornado the diameter was about twice as large as the pool width. Because the intensive circular wind generated by tornado sucked the flame from the pool, and the flame slided out forming an apparent burning area on the floor. The flaming tornado wore the black smoke.

Table 3 shows average radiative heat fluxes at the foot of the flame of gasoline pool fire. Averaging on the radiative heat flux was done for the active burning period. Convection flow gave fluctuations on the radiative heat flux at the foot of flame, but about 9 - 11 W/cm^2

Table 2 Burning Rate and Wind Condition

Exp.	pool location	burning rate [mm/min]	natural wind direction	natural wind velocity [m/sec]
#1	c	5.7	SSW	2.4
#2	m	5.8	NNW	2.5
#3	f	7.4	SSW	1.5
#4	c	4.9	NNE - NE	1.8
#5	m	5.2	SSE	3.7
#6	f	6.7	SSW	1.3
#7	m	5.3	SE - SSE	2.3
#8	f	6.4	SSW	5.6
#9	f	6.4	SSW	6.5
#10	f	5.3	ENE - NNE	4.1

c:at the end corner m:middle position
f:at the foot of opening

from 900 liters pool fire were obtained. It had been expected that the heated walls and ceiling produce extensive reradiation to the fuel surface and which results in greater rate of gasification. We estimate the average burning rate of 5.38 mm/min from the experiments of #1, #2, #4, #5, and #7, therefore, mass burning rate per unit area is evaluated as 0.069 Kg/m^{2}sec. Burning rate in an open feild gasoline fire is about 4.0 mm/min [ref.1] - 4.3 mm/min [ref.2] for the turbulent flow region. Burning rate which we obtained is about 1.25 - 1.35 times greater than the ones obtained in an open field burning of turbulent gasoline fire.

The observation suggested that two factors of radiative heat flux to the fuel and wind effects by convection dominate the burning rate. The hot flow velocity under the ceiling at the opening was about 5.4 - 6.3 m/sec as the burning pool was set at the end corner, and 1.7 - 3.9 m/sec as the middle position pool. As we employ the rough average flow velocity of 5 m/sec based on the above data, rough average temperature of 700 ^{o}C, and the hot smoky flow thickness of about 2m from observation, hence, the outward mass flow was estimated as 52.6 kg/sec. If we assume that the same amount of inflow air are given into the space, average inflow velocity is estimated as about 1 m/sec. There are various discussions of the wind effects on the burning rate [ref.3,4,5]. According to the equation which Blinov and Khudiakov [ref.5] proposed, it was estimated that the wind effects gave 4% greater burning rate in the case of inflow velocity of about 1 m/sec. Therefore, the burning rate of about 4.16 mm/min was expected as a result of wind effect. The burning rate, we obtained, at the end corner was over 5 mm/min, it is concluded that the difference in burning rate observed is mainly governed by radiation.

As the pool at the foot of the opening was employed, gasoline flame crept out of the pool and formed an apparent extended burning area on the floor. The flame tornado stood not on the original pool but on the floor about 2 - 3 m away from the edge of the pool. It was likely that the optical flame thickness above the pool was not deep compared with the other test. However, the burning rates of experiments #3 and #6 were greater than the one of the other experiments. We observed intensive circular wind around the tornado which made an extended apparent burning area on the floor. It is supposed that the wind resulted in an increased

Table 3 Radiative Heat Flux at the foot of Flame

Exp.	ave. (W/square cms)	max.	min.	periods [min:sec]
#1	5.73	11.79	2.38	0:20 - 6:10
#2	11.10	16.26	4.79	0:20 - 9:40
#3	7.27	15.06	1.64	0:20 - 8:00
#4	11.00	16.79	3.32	0:30 - 12:00
#5	9.09	16.53	3.51	0:40 - 10:00
#6	8.98	14.78	2.33	0:20 - 8:10
#7	10.70	16.80	1.98	0:30 - 10:30
#8	8.02	12.21	1.93	0:20 - 8:40
#9	5.69	12.32	1.43	0:20 - 8:50
#10	9.97	13.17	5.39	0:20 - 3:00

vaporization from the original pool. It is likely that the observations of the movements of sand in the circular wind, although we did not measure the wind velocity around the tornado, suggested the wind velocity exceeded over 10 m/sec. If we adopt the estimated wind velocity as 10 m/sec, it may give about 5.5 mm/min burning rate. The burning rates in experiments #3 and #6 gave 6.7 - 7.4 mm/min which are 1.55-1.7 times greater than in an open field burning. Therefore, in these cases, wind effect was the main factor which gave greater burning rate.

3-2. Passive and Active Fire Protection

External flame is an important factor of fire spread to the upstairs. In order to evaluate the passive and active fire protection systems for upstairs from the flame/hot current given by gasoline pool fire, experiments #8, #9 and #10 were carried out with a passive and active fire protection system. A pent roof of 1.5 m and 1.0 m were attached to the facade above the soffit of the opening. In experiment #10, the water drencher system of 800 l/min with 6 heads were set instead of the pent roof as an active fire protection system, respectively.

a) <u>Passive fire protection.</u> The pent roof was made of ALC panel of 100 mm thickness. The fire source and measurement systems were set as similar as to the ones in experiment #6 to compare with each other. However, when experiments #8 and #9 were carried out, natural wind velocity were relatively higher than #6 as is shown in Table 2. It may give the merits to compare the rough tendency in temperature maps of the facade with and without the pent roof, but the difference in wind velocities between experiments #6 and #8/#9 was not negligible small. Therefore, in these cases, we do not compare the temperature differences on the facade obtained with and without the pent roof. Fortunately, we found out the period of 5 minutes from experiments #8 and #9 when the

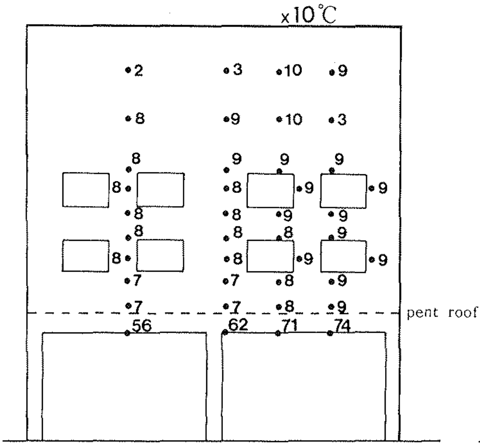

Figure 2. Temperature map on the surface of the facade with 1.5m length of pent roof

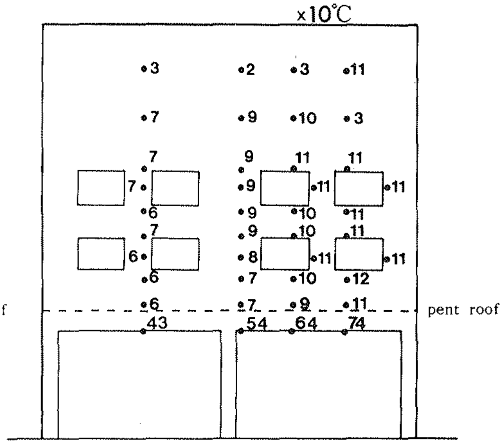

Figure 3. Temperature map on the surface of the facade with 1.0m length of pent roof

natural wind condition was almost same with each other. Temperatures on the facade were averaged in the period of 5 minutes. Figure 2 shows the temperature map on the facade with the pent roof of 1.5m, and Figure 3 shows the similar map with the pent roof of 1.0 m. It is likely that the temperatures obtained with 1.5m pent roof are slightly lower than the one with 1.0m pent roof. As Yokoi [ref.6] had reported that the pent roof reduces the radiation to the facade, it has confirmed also that temperatures of the facade were reduced by the pent roof. In both cases, the flaming tornado inclined by the wind and moved away from the wall. Therefore, both temperatures show the relatively lower than the one of experiment #6, but, it must remember that natural wind velocity in the case of experiment #6 was moderate and hence the flaming tornado stood almost vertically.

b) <u>Active fire protection.</u> The water drencher system was set above the soffit of the opening. Water was sprinkled at the rate of 800 l/min from 6 heads. The fire continued for three minutes and half and then drenching started. Figures 4 and 5 show the temperatures before and after the water drenching. It is clearly observed that the temperatures on the facade dropped 400 - 450 to 70 - 100°C within a few minutes. It is considered that the drencher system was very effective to reduce the external heating to building.

3-3. Radiation to Facade and through Windows

Radiative heat flux through the window glass of a room is an important factor for the fire spread into the room. As a fire scenario, it could be supposed that the combustible curtain is set at the window side, and radiation heat flux through the window glass is adequate to cause the fire on it, the fire will start without the breaking of window glass. To evaluate the possibility of fire by radiation through the window glass, two radiation heat fluxes were measured at the surface of

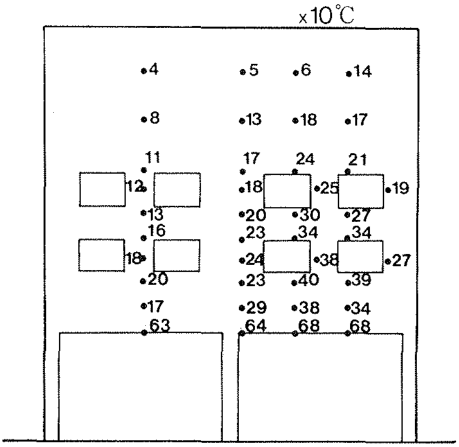

Figure 4. Temperature map on the surface of the facade before the water drencher starts

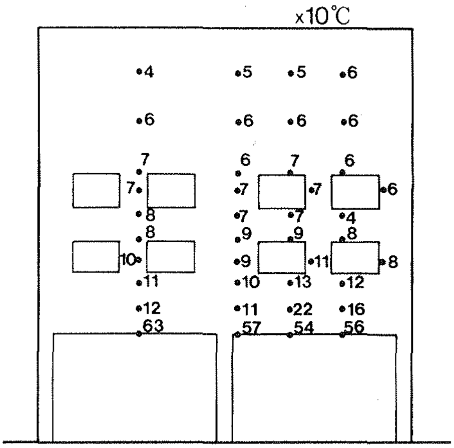

Figure 5. Temperature map after the water was drenched

the facade, and other two were measured in the room through the window glass on the second floor. Figure 6 shows the time histories of the radiation heat flux of those four radiation meters obtained from experiment #6. In the second floor room, radiation heat flux indicated 0.25 - 0.35 W/cm^2 through the wired window glass, and at the same time, radiation heat flux was obtained as 1.4 - 1.7 W/cm^2 on the facade. The wired glass kept still without breaking for several experiments. Therefore, within the data we obtained, it is expected that there is little possibility of the fire development through the wired glass window even the flame touches the window.

4. CONCLUSION

The wired glasses of windows on the second floor were heated by radiation of about 9 W/cm^2 instantaneously from flaming tornado, and some cracks were observed but the wired glasses were not broken down and which performed resistance against the fire propagation into the room with and without the pent roof or the drencher system. Therefore, no smoke and no excess temperature were observed in the rooms on the second and third floors.

Burning rate of the gasoline pool fire in the semi-enclosed space indicated about 1.25 - 1.35 times greater than the one of a free burning in an open field. When the burning pool located inside the station, radiation is the main effect which gave the greater burning rate but wind given by the convection flow is also considerable effect to the burning rate.

When the burning pool located at the foot of opening with wind from behind or side of the building, the flaming tornado of about 18-20 m high was observed. This may have a fire propagation potential to the

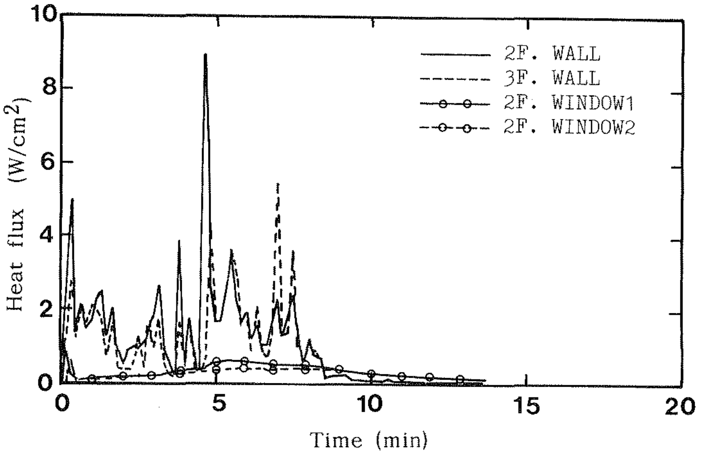

Figure 6. Time histories of the radiation heat fluxes on the facade and through the window glass on the second floor

plastic advertising panels attached to the facade of buildings. The flaming tornado may involve cars and pedestrians in the fire accident when they were at the front of the gasoline station. Therefore, the pool which is prepared for collection of leaked gasoline should be located inside of the station.

It has been conducted that many experimental and theoretical studies on gasoline pool fire without or having little wind effects. These are not quite helpful to the real gasoline fire. A gasoline station in real has a large opening with having a natural wind effect. Results of the full scale model test suggested quite obviously that wind effect is extremely important factor to assess the fire potential to the building.

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