Measurement 93 (2016) 340–350

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Performance measurement of a smoke extraction system for buildings in full-scale hot smoke test

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ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 16 June 2016
Accepted 8 July 2016
Available online 12 July 2016

Keywords:
Smoke extraction system
Hot smoke test
Smoke layer
Plugholing
Makeup air

ABSTRACT

The current inspection method for a smoke extraction system in Taiwan measures whether the air flow of the smoke vent conforms to the design value. However, this method is inapplicable to natural smoke extraction systems. As the plugholing effect is disregarded, adequate air flow cannot ensure that the system will exhaust smoke effectively during a fire. Hence, a full-scale hot smoke test for smoke extraction systems is necessary. Some international test criteria are formulated using visible smoke and alcoholic fuel which is pollution-free after combustion. The effectiveness is judged only by visually observing the smoke's flow direction, which is indeed unscientific. This study used a string of vertical smoke layer measuring instruments composed of several approved photoelectric smoke detectors, as well as a light attenuation measuring device composed of illuminance meters to conduct tests on the effect of makeup air. The results proved that the former one uses different height induction times to judge the position of the smoke layer effectively, while the latter one uses the light attenuation rate to distinguish the smoke density instantly and accurately. The obtained experimental data were consistent with the onsite smoke distribution. The two sets of equipment designed in this study can be used for full-scale hot smoke tests to obtain performance data for a smoke extraction system.

1. Research on motivation

1.1. Importance of building smoke extraction systems

The smoke at a fire scene can be a fatal factor. The hazards of smoke include high temperature, toxicity and obscuration. The first two hazards can cause immediate death; the last hazard affects the evacuation of victims and the rescue behavior of rescue personnel [1–4].

A building's smoke extraction system can protect the lives of personnel. In an evacuation process, a smoke extraction system will keep the escape route free from smoke which obscures vision. An environment without smoke allows firefighters to have better rescue efficiency. A good smoke extraction system can postpone or prevent flashover which is the key factor to the overall development of a building fire [5,6].

1.2. The smoke extraction system inspection method and deficiencies

In Taiwan, the specifications of a smoke extraction system refer to Item 3 of Article 126 of Japan's ''Building Standard Law Enforcement Order" [7]. The control of smoke at the scene of a fire is divided into natural and mechanical types. If a mechanical system is used, the smoke exhaust capacity is related to the area of the smoke compartment. The system capacity is higher than 1.0 m^3/min per square meter if one zone needs smoke exhaust. When more than two zones need smoke exhaust, the air flow is the largest compartment area multiplied by 2.0 m^3/min per square meter [8].

The present test method of a smoke extraction system measures the average air velocity at five points of the smoke vent, which is also known as the ''five-point measuring method", as shown in Fig. 1. The measurement lasts 30 s at each measuring point and the average air velocity of the five points is taken and multiplied by the area to obtain the air flow value. The air exhaust capacity is checked with the original application [9]. The change in the extraction rate or boundary conditions during the test is not considered pertaining to the inspection standards.

However, the present inspection method has the following problems:

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http://dx.doi.org/10.1016/j.measurement.2016.07.040
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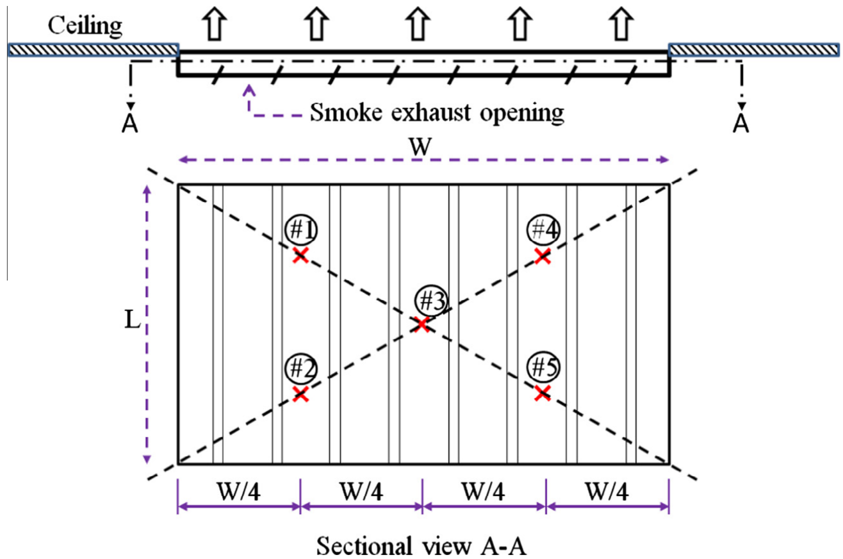

Fig. 1. The five-point measurement method in smoke exhaust.

- The exhausted flow applicable to the "five-point measurement method" is adopted for a mechanical system. Since the airflow through the natural vent is affected by the temperature and pressure difference between indoor and outdoor environments, the system performance cannot be confirmed.
- The plugholing effect of the smoke control theory is not estimated sometimes. The overall effect of higher extraction rates is positive as long as the vertical air through the vent is not too high. The smoke vent does not pump smoke, but pumps a great deal of air under the smoke layer if the vertical air is too high, as shown in Fig. 2 [10,11]. The overdesign rate of smoke exhaust measured at ordinary times is supposed to have a positive effect, but at a fire scene, it worsens the environment.
- The indoor air flow is a three-dimensional flow phenomenon since the fire scene is full of hot air and smoke [12]. For the smoke exhaust effect, the overall space should be tested, which is similar to evaluating "air age" in building ventilation systems [13,14]. If the exhaust smoke level is only checked at a single pot, instead of the entire space, the performance of the indoor smoke extraction system cannot be evaluated effectively.

1.3. International full-scale test method

Some countries have developed full-scale hot smoke test standards to test the ability of smoke extraction systems to control indoor fumes. The common international full-scale test methods include the 4391-1999 Smoke Management Systems Hot Smoke Test (Australia), the JIS A4303-1994 Inspection Standard of Smoke Exhaust Equipment in Full-Scale Tests (Japan), and the GA/T 999-2012 Test Method (China) for verifying field performance of smoke management systems [15–17].

The test often uses a combustion pollution-free fuel, such as methanol or ethanol, which generates a colorless nontoxic fire plume. A tracer particle for visualization is then injected into the

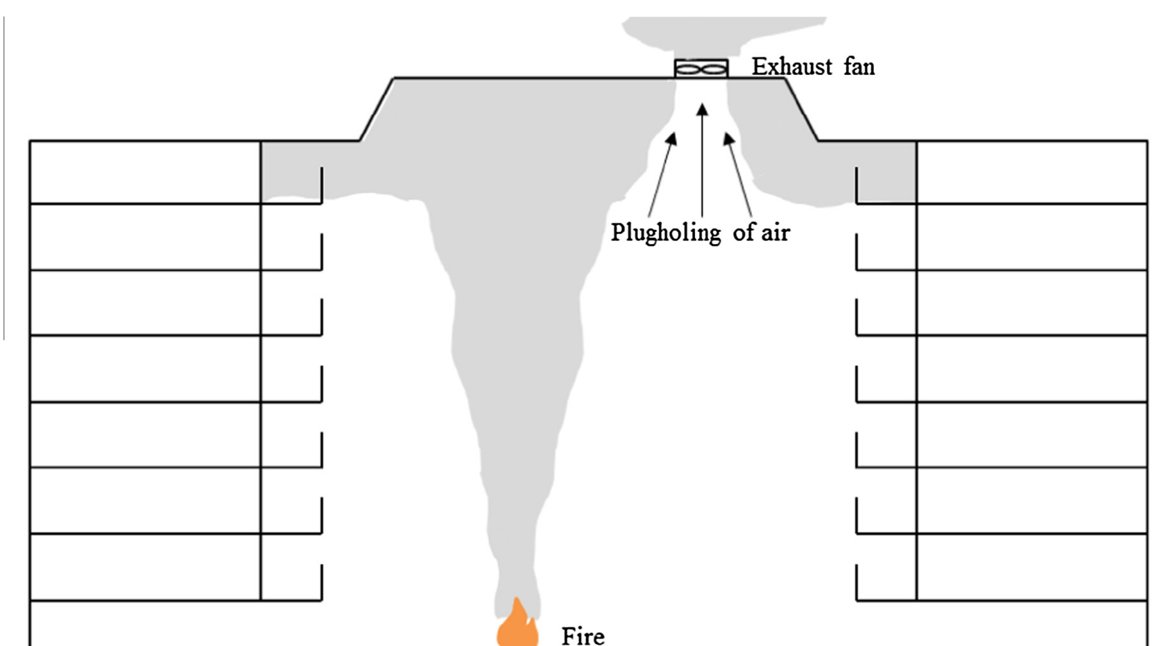

Fig. 2. Plugholing phenomenon of air into smoke exhaust.