BUILDING EVALUATION FOR MANUAL SUPPRESSION

by

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ABSTRACT

Recent improvements in equipment used by firefighters has increased the value of manual suppression in buildings. However, because there is no evaluation method available, the effectiveness manual suppression can not be incorporated into a fire safety analysis of a building. This following thesis develops a method for evaluating manual suppression in buildings. The evaluation is done through an analysis of the paths through a building firefighters will use to attack a fire. The analysis considers the building, fire, and fire department factors influencing progress towards the fire. The fire attack path analysis yields a value relating the relative difficulty of a path.

Key Words: Manual Suppression Evaluation Fire Attack

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CHAPTER 1

INTRODUCTION

The application of water on fire through hose lines is the primary service provided by a fire department[1]. Certainly, fire department extinguishment of fire is most critical when the fire occurs in a building. And better firefighting equipment has improved the value of this service. With current equipment, firefighters can attack and extinguish an sizable fire located behind a barrier of smoke and heat. Clearly, a building can either help or hinder the extinguishment process. And a building that helps a fire department in extinguishing a fire should offer a higher level of firesafety. Therefore, buildings should be evaluated for their influence on the primary fire department service of water application. Yet, there is no method available for conducting such an evaluation.

According to the Building Firesafety Engineering Method (BFSEM), buildings have an ability to allow a fire department to extinguish a fire[2]. In the BFSEM, this ability is expressed in a graph called the Manual

Suppression Curve (M Curve). The M Curve relates the probability of fire department extinguishment to fire size. If a building's design or layout is altered, then it's M curve can change. A design change may make delivery of water on a fire, or fire attack, more difficult, and therefore take longer, or the change may speed the fire attack along. The real problem in slowing a fire attack is that it is not confronting a static challenge. The fire is growing. And as fire grows, the probability of quick extinguishment by a fire department shrinks.

1.1 PROBLEM

Building design factors, which make it difficult for a fire department to extinguish a fire, once recognized (usually after a series of tragic fires) are remedied through building and fire codes[3]. The need for firefighter elevator recall for high rise buildings was recognized and corrected in this manner[4]. However, other design features, which also influence the potential success of a fire attack, are not presently addressed in codes.

With recent improvements in firefighting equipment new building features have become significant For example, prior to the wide spread use of Self-Contained-Breathing-Apparatus (SCBA), it really didn't matter how far down a smoke charged corridor the fire space was, no firefighter was humanly able to advance the attack line 20 feet or 200 feet toward the fire space. Today's firefighting equipment has removed some of the human limits to making an aggressive interior fire attack. Now, other factors have replaced long standing human factors in limiting manual suppression effectiveness.

When an obvious handicap to firefighting in buildings is addressed, the improvement in the ability of the building to assist the fire department is so dramatic, it is often taken for granted. The presence of firefighting standpipes in high rise buildings demonstrates this point. The problem with the less obvious features, is not only their identification, but their need for careful evaluation.

For example, consider the situation of a fire in a room at the end of a corridor as is found in Figure 1. Two different fire attacks are shown. With respect to the situation the only difference is that in Attack-2 the door is locked, and in Attack-1 the door is open. The open door of Attack-1 allows the products of combustion to contaminate the corridor. Which attack has the higher extinguishment probability?

Both attack paths have pluses and minuses to consider:

ATTACK-2

+ attack can be advanced with dry line
- person must stay or return to open valve in stairwell
+ closed door keeps corridor clear
- closed door must be forced open

ATTACK-1

+ no barrier between corridor and room
- smoke and gas must be passed through to reach room
- line must be advanced after charging
+ no one must stay with or return to valve

Moreover, Attack-2 cannot be evaluated without considering the following items related to the door:

construction material
direction of swing
entry tools available

As is seen above, a small change in a building feature causes many factors to be considered in order to evaluate the effect of the change on manual suppression effectiveness. Clearly, the evaluation of manual suppression needs a well structured framework.

1.2 BUILDING FIRESAFETY ENGINEERING METHOD

There is no complete and proven process for evaluating the overall level of firesafety for a building. A process such as this is needed to make reasonable comparisons of design alternatives as they relate fire risk for a building and its occupants. Currently, the Building Firesafety Engineering Method (BFSEM) is undergoing refinement to fill this need. The reader is referred to the BFSEM workbook for a detailed explanation of the method[5].

As is noted in the BFSEM workbook, fire in a building is a very complex system involving a large number of interacting components. The method breaks down this complex system into logical subsystems. These subsystems include the building, the fire, and manual suppression. Generally, manual suppression means extinguishment by a local fire department.

The BFSEM structures through the uses of network diagrams. These diagrams represent event trees and fault-success trees. The method network diagram of interest to this thesis shown in Figure 2. The events described in Figure 2 are critical to the manual suppression process. Certainly, the fire department must be notified in some way before any response can begin. And agent application denotes the start of fire department impact on a fire. Finally, the goal at almost all fire department responses to fire is extinguishment.

The BFSEM represents fire department actions as points on a time line. The segments of the time line from notification until arrival have evaluation methods available. However, there is no method for evaluating the time line between arrival and extinguishment. Determining the moment agent application starts is a concern, because prior to this point on the time line, the probability of fire department extinguishment of the fire is zero.

1.3 SCOPE OF WORK

This thesis develops a method for evaluating the influence of a building and fire on manual suppression effectiveness. The development occurs in three steps as follows: (1) the factors to be evaluated are established, (2) the output of the system evaluation is defined, and (3) the evaluation process leading to the output is formed. However, prior to development of the evaluation method recent firefighting equipment improvements that have increased the value of manual suppression are discussed.

Manual suppression is one component in the larger building-fire system. The manual suppression part of the system is composed of many tasks which must be carried out for a fire to be extinguished. The suppression tasks include: locate the fire, attack the fire, control the fire and extinguish the fire. Nevertheless, in some situations manual suppression reduces to just the attack task. In these instances extinguishment occurs rapidly after the first water is applied to the fire. Therefore, when extinguishment is felt to occur with the first application of water the only task that must be evaluated is the fire attack.

The measure of the fire attack evaluation is a number relating attack path difficulty. This number can be used to compare building designs for attack path difficulty, as well as a conversion to time line values. The number is based on the fact that the effort required to complete a fire attack can not be quantified by considering only the distance covered by the attack. To evaluate an attack path, the condition of the building, the fire conditions, and the fire department resources and operations at many points along the attack path must be considered. The conditions encountered during a fire attack serve to "alter" the distance. This altered distance is caused by features encountered along the path, and is defined as the effective path distance. The ratio of the effective distance of a path to the actual path distance is defined as the path difficulty.

The evaluation process reduces the actual conditions found in a building fire to a simpler, but "equivalent" condition. This concept is similar to the system of equivalence used in automatic fire sprinkler piping design. In the evaluation of a sprinkler pipe design, when a component causing excess friction is encountered it is replaced with an equivalent length of pipe. In this evaluation of a fire attack path, when a factor changing progress along the attack path is encountered it is replaced with an equivalent length of distance.

The process evaluated the equivalence in stages. That is, each factor influencing the fire attack is addressed separately. This is similar to the training process undergone by firefighters, where they learn the basics of a fire attack, and then additional layers of complexity are added to the attack as they progress in skill[6].

The ability to compare the paths in a building to a fire location allows the identification of the "best" route to the fire. However, identifying the best path to the fire is not the same as identifying the most probable attack path. Firefighters choose a path to a fire based on what is known about the location of the fire and what is known about the building. The process is comparable to way finding in building occupant emergency egress. Locating a fire is a rational process, and probabilities can be developed for each decision point encountered as a firefighter progresses through a building.

With a method to evaluate attack paths and their selection processes in place, the challenge to a building designer will be to create circulation paths with attention to fire attack paths, and to assist firefighters to select the best available path to a fire.

It is hoped, the method for evaluating manual suppression in buildings outlined in this thesis will lead to the completion of the manual suppression time line. Furthermore, incorporating some of the concepts and evaluation framework into the BFSEM is possible.

This paper is written for a reader more familiar with building design than with firefighting. The goal is to enable an engineer with relatively little practical firefighting experience to be able to recognize the building design features that will influence a fire attack. In this way, a building can be evaluated for its ability to assist the local fire department in doing its suppression job.

CHAPTER 2

IMPACT OF MANUAL SUPPRESSION

Traditionally the effectiveness of a fire department has been associated with response time. It was felt the faster the arrival of the fire department, the more likely the fire will be quickly extinguished. Given the limited interior firefighting capabilities of even the recent past, average response time did seem to be a reasonable indicator of overall effectiveness. However, with the current potential for aggressive interior firefighting the time after arrival has changed in value. The speed with which firefighters are able to carry out their post-arrival duties to achieve an effective fire attack will influence the ease of extinguishment and resulting damage.

During recent years, improvements in equipment used by firefighters for interior fire attack has had a tremendous impact on their abilities to approach and extinguish fire in buildings. Advances in Self-Contained-Breathing-apparatus(SCBA), and firefighter protective(turnout) gear allow firefighters to penetrate the heat and smoke of a fire to a far greater extent than only a few years ago. In addition, the increased volume of water discharged through the hose and nozzles currently used by the fire service can deliver a knock-out punch to a large area of fire.

2.1 SELF-CONTAINED-BREATHING-APPARATUS

An examination instruction manual for fire service applicants which was used in Massachusetts through the early 1970's, contains the following advice for operating in a smoke filled room, "With a smokey mattress(fire), many times the breath can be held until the window is reached and opened.[7]" Firefighters are not immune to the toxic and irritant effects of smoke and fire gases. Breathing apparatus offering respiratory protection to firefighters have been around for over a century. The devices were usually masks, based on one of the following principles: filter, fresh air hose, self-generating oxygen, or stored compressed air or oxygen.

Each type of mask had advantages and disadvantages, and even when they were available to a firefighter they often were not worn. It was not until 1976 that a SCBA was introduced that could truly meet the needs of firefighters[8]. The new SCBA was small, reliable, lightweight, and held thirty minutes of clean air. Acceptance of the new SCBA by the fire service came quickly. A photo journal on the New York City fire department, which was published in 1978, contains only a few photographs with firefighters wearing an old style SCBA[9]. Today, the need for SCBA is universally accepted, and for a firefighter to be photographed operating at a fire without one is considered an embarrassment.

There are still environments in which firefighters cannot enter. The presence of hazardous materials, which are defined as materials that may pose an unreasonable risk to health, safety, or property, will stop a fire attack from being made[10]. Nevertheless, firefighters have capabilities to advance an attack line through smoke that they did not possess as recently as twenty years ago.

2.2 TURNOUT GEAR

Throughout most of the history of firefighting the gear worn by firefighters was designed to shed water. From the shape of the helmet to the tall rubber boots, keeping the wearer from getting wet was the gear's primary purpose. Without an effective way to get through smoke to a fire located in a building, firefighting was often a defensive operation involving large amounts of water delivered from outside the building[11]. In addition, any insulation present was intended to keep the wearer warm in cold weather, and not to keep the firefighter cool in the face of flame. Furthermore, it was common for firefighters to remove the insulating liner during warm months of the year. The limited thermal protection was not a problem until the introduction of SCBA. A firefighter equipped with SCBA was now able to advance through smoke, but was unable to endure the heat at the advanced position for any long duration.

The deficiencies in turnout gear made so apparent with in introduction of SCBA have been corrected. In fact, turnout gear now available will allow a firefighter to remain in a room until flashover occurs. However, the situation now exists where the gear so isolates the firefighter from the environment, there is a growing concern they may be over protected[12]. The ability to endure in hot, smokey environments enables a firefighter to maintain an aggressive attack in a situation that may result in exposure to flashover conditions.

2.3 HOSE AND NOZZLES

At one time the firefighter had no choice in hose and nozzle. Firefighting was done with a big line(2 1/2-inch) and a smooth bore nozzle. During this period, relatively little interior firefighting was undertaken. However, the increase in interior firefighting brought about by improved firefighter safety equipment also has been followed with changes in the hose and nozzles available to the fire service.

Interior attack hose lines require mobility. Once charged the standard 2 1/2 inch hose line becomes very difficult to move through a building. Using a smaller diameter hose for interior work increases the mobility, but at a cost of water flow rate. For an effective fire stream, which has reach and penetration, the nozzle diameter is limited to a maximum of one half of the hose line diameter[13]. Because flow area is related to the square of hose diameter, small changes in hose diameter produce large changes in the water that can be delivered through a nozzle.

Nozzles can be categorized by several characteristics. However, none of a nozzle's defining features none is more important than flow rate. Water flow, normally expressed in gallons per minute extinguishes fire. The rate of flow for nozzles now available for interior firefighting has tripled during the last thirty years.

Through the 1960's the standard attack line in the fire service was based on 1 1/2-inch hose and a nozzle flowing about 60 gal/min. Prior to recent safety equipment improvements, the 1 1/2 hose line was considered adequate. Today, nozzles flowing 180 gal/min supplied by 1 3/4-inch hose lines are more typical, tripling the flow rate. Before safety equipment was improved an aggressive attack was not possible and the old attack line was adequate. However, with the advent of modern protective gear and the greater flow rate, interior fires can be attacked and extinguished more readily.

2.4 FIREFIGHTING CAPABILITIES

In recent years, there have been additional improvements in firefighting technology. Communications have improved with the availability of portable two-way radios. More sophisticated forcible entry tools at are now available. With all the gains in technology, it would appear today's firefighters are each able to do the work of several of their predecessors

A properly equipped, staffed, and trained fire department should be able to enter a building, penetrate the hostile fire environment to the fire, and deliver a knock-out blow to a fully developed fire in a room. Depending upon fire department resources, it may be able to extinguish several fully involved rooms before the fire can extend even further. It is now possible to extinguish a fire in a very large room more readily. This ability was not available as recently as a generation ago.

CHAPTER 3

THE EVALUATED FACTORS

A method for evaluating the fire risk for a building and its occupants will include consideration of the building, the occupants, the fire, and the fire department. Moreover, the evaluation process must include the complex interaction between these components. The component interactions have not been given appropriate attention in analytical studies. Some of the interactions are possible to evaluate. Many are not.

The interaction of a building and fire can be analyzed in numerous ways. For example, considering a building's influence on a fire, methods of analysis exist for smoke movement and fire growth. Likewise, materials reactions to fire also has been investigated. Evaluation methods exist for a number of the building-fire system components[14]. On the other hand, interaction between a fire department and the other components has received little attention. There is no evaluation process to determine a building's influence on fire department operations during a fire[15]. Certainly, the dynamic aspect of fire coupled with the human element of a fire department suggests a difficult evaluation.

Firefighters train on firefighting principles and practices. In addition, there are standards of knowledge established for firefighters[16,17]. These observations indicate that at some level, firefighters and fires are predictable. Members of the fire service say "every fire is different". Nevertheless, many aspects of firefighting repeated at every fire. Understanding the repeated aspects of firefighting is the first step towards the evaluation of the effectiveness of manual suppression in buildings.

3.1 THE FIRE DEPARTMENT

Several key tasks must be executed for the actions of a fire department to result in the quick extinguishment of a building fire, several tasks must be completed. However, prior to the start of the physical tasks of firefighting a mental analysis of the situation must be untertaken by the fire officer in command.

The analysis of a fire situation is called "size-up" throughout the fire service· Lists of the factors to be considered in the evaluation of a fire have been developed. Table 1 contains an example of one such list[18]. Not surprisingly, the size-up factors relate to the building, firefighting resources, and the fire. Because fire departments can not be expected to handle any size fire, buildings ignoring size-up factors may have conditions that will contribute to a major loss.

The most important outcome from an initial size-up is the selection of a strategic mode. Based on an analysis of the fire situation and the available resource situation, the fire commander will decide whether to make an aggressive attack or a protective stand. These are referred to as offensive and defensive modes of operation. Often the operating mode determines whether the building will be entered, and certainly influences the extent of fire damage. Concerns related to the building, resources, or fire can stop a fire attack before it starts. It is important for a building designer to understand the fire size where the attack-protect change occurs. The fire size where the change occurs is dependant on the building and the fire department[19]. A fire risk analysis should include the capabilities of the local fire department.

3.1.1 THE TASKS

A fire department's basic strategy for a building fire is the following[20]:

Locate

Confine

Extinguish

This is a simple strategy. However, carrying out the strategy is rarely simple. There is a wide range of difficulties for each part of the strategy. In any given situation there can be a large difference in the difficulty between each part. For instance, in a lumberyard it is very easy to locate the fire, but extremely difficult to extinguish it.

According to the BFSEM the success of the following events are critical for manual suppression:

Fire departmentis notified

Agent application does occur

Manual extinguishment does occur

Agent application is important to the analysis because the fire department is not impacting the fire until that condition occurs. That is, the probability of the fire being extinguished by the fire department prior to agent application is zero[21].

Incorporating the basic fire department strategy with the building evaluation gives the following:

Fire department is notified

Fire is located

Agent application occurs

Fire is confined

Extinguishment does occur

Limiting this first part of the analysis to the time period after the arrival of the first fire department apparatus, and choosing the traditional fire department compact wording gives the following:

Locate

Attack

Control

Extinguish

All action taken by a fire department leading to the suppression of a fire can be assigned to one of the above tasks.

3.1.1.1 LOCATE

Few persons not associated with the fire service would select locate as the most difficult task in firefighting. Yet, this was the case in a 1993 survey of fire chief's opinions[22]. Place a small fire in a large building and the task becomes very time consuming for firefighters without help. There are two ways to determine the location of a fire. The fire can be located by firefighters sensing the fire's location, or firefighters can be informed of the location. If incomplete location information is available, then firefighters must fill in the remainder by a reconnaissance of the building. Better location information can be supplied only by a systematic search of the building for the fire.

Firefighters sense a fire's location by seeing flame or smelling smoke. In some cases, the smell of smoke can lead the firefighters to a fire. In other cases, it may disguise the location. Clearly, not all buildings are equal in their ability to deliver an indication of fire to the arriving firefighters. An overview of the exterior is the first step in locating a fire. Obtaining a view of all sides of a building is dependent upon access and not always easy. In addition, the probability of the fire being visible form the exterior drops rapidly as area increases. Floor area increases much faster than perimeter. If the fire area is on the building perimeter, but the walls lacks windows then this kind of visible fire locating can not occur.

Another way of locating a fire can be by direction to the fire by a person or an electrical/mechanical device. The more accurate the direction (i.e. the more information given to the firefighters) the faster the location of the fire can be scouted and confirmed. Also, it would be a rare group of firefighters that did not have two activity levels, one relating to the report of a fire and the other relating to a confirmed fire. The quicker a fire is confirmed, the faster the shift to the higher level of activity is made. Reliable information that can be easily related to the building is crucial to the fast location of a fire.

3.1.1.2 ATTACK

Application of water on fire through hose lines is the primary service provided by a fire department. This is the fire attack. Mounting a fire attack requires manpower, equipment, and water. Each hose line in the attack can thought of as having two stages, set-up and execution.

The set-up means moving manpower, equipment, and water to the perimeter of the smoke and heat. Generally, high-rise buildings or very large buildings offer the most challenging and time consuming set-up logistics.

The execution is the movement of a hose line through the smoke and heat to the fire. The execution stage of an attack is complete when water is first applied to the fire. All actions and results after the first line is in operation are considered part of the control task.

3.1.1.3 CONTROL

The control task for a large fire occurs under the most complex state for the building, fire, and fire department. During an attempt to gain control of a large fire, the components of the system are interacting at their most intense level. A fire is considered controlled when its growth in size or area has stopped. There may be areas of uncontrolled burning within the fire area, but the extension of the fire is not occurring. Effective and efficient use of suppression resources, as well as the effectiveness of barriers, are vital in controlling a large fire.

A key item in controlling a large fire is ventilation of the fire area. Once the first attack line has opened up on the fire, a two layer fire environment will be upset. In addition, the dry heat of the fire will be replaced with the steam heat from the extinguishing process. If the attack must continue to gain control over the fire, then the new firefighter-made environment must be vented.

Among the fire department activities must be checking for fire extension. Fire spread can be either vertical or horizontal. All possible avenues for vertical and horizontal fire extension must be located. Because it is time consuming to regroup firefighters after they have completed an assignment, the check for fire spread is likely to be done by "fresh" firefighting forces, or the it will not be done. Therefore, checking for fire extension can rapidly use up fire department manpower.

Vertical fire spread is the most difficult to control through manual suppression. A fire on more than one floor of a building requires firefighters to work above the fire. Operating above a fire is considered to be the most dangerous firefighting operation[23]. Since heat and smoke tends to spread vertically through the building, the area above the fire can be more dangerous to firefighters than the fire area. The danger and logistics in controlling vertical extension causes a large drop in manual suppression effectiveness. Therefore, the chance of vertical fire spread should be minimized in any building design.

Reliable building barriers enable many sizable fires to be controlled quickly with water application from the first attack line. That is, once the first line is opened on the fire, the fire ceases to be a threat to the building or fire department. In situations where extinguishment is quickly reached, an evaluation is simplified. The evaluation is simpler because no consideration of the more complex conditions during the control task is needed.

3.1.1.4 EXTINGUISHMENT

The goal of the overall fire strategy is extinguishment. Also, without an advance towards extinguishment any control gained over a fire may later be lost. A fire may go-out in two ways. First, the fire department may advance to the fire area and by direct application of water, black-out the fire. Secondly, the fire may burn-out due to consumption of available fuel.

Extinguishment of a large fire by the fire department places a great deal of stress on manual suppression resources. The fire department must have adequate manpower and water to sustain the extinguishment process. If extinguishment is not reached before the firefighters manning hose lines use up their SCBA air supply, then additional manpower will be needed to continue extinguishing the fire. Certainly, if a fire department exhausts the available water supply without extinguishing the fire, progress made towards extinguishment may be lost.

Extinguishment of a large fire by allowing it to burn-out stresses the building barriers. When manual suppression resources are insufficient to extinguish a controlled fire, the ability of building barriers to prevent spread becomes a significant factor. Often, barriers serve only to slow fire spread, not to stop it completely

The final phase of extinguishment, overhaul, is when the last hot spots from the fire are searched out and extinguished. This is a labor intensive and time consuming process. If the department has expended all of its resources in order to reach this phase of manual suppression fire, there is a risk of the fire may rekindle.

3.2 THE FIRE

At first glance fire appears to be unpredictable. However, all fires have predictable characteristics. Fire growth has been investigated at length, and various methods of qualification and quantification are available[24]. The most important characteristics of fire that influence manual suppression are the speed of fire growth and the spread of combustion products through a building.

3.2.1 FIRE SIZE

Over time a fire passes through several stages which can be related to fire size. The events are as follows: ignition, established burning, full room involvement (flashover), and fully developed fire (post flashover).

There are several fire growth models available that can available. Because of the speed with which a fire grows, and the common delays in notification, a fire department often must deal with a fully developed fire. For a fully developed fire, it is usually more convenient to consider size as an area of fire involvement, rather than a heat release rate.

With regard to fire suppression, there is an important fire size not listed above. Somewhere in increasing fire size considerations, the effectiveness of fire suppression will deteriorate. For a specific fire situation, as fire size is increased, there is a size where the expectation of a quick extinguishment decreases. This is called the Critical Fire Size(CFS)[25]. The CFS is unique to every system of fire, building, and fire department.

3.2.2 PRODUCTS OF COMBUSTION

Fire products of combustion are made-up of thermal flame-heat and non-thermal smoke-gas components. The fire products follow natural paths through the building. The combustion products can make a large area, not directly involved with the fire, untenable very quickly.

The heat and smoke conditions found near a fire do not challenge the safety equipment currently available to firefighters. The equipment insulates firefighters from the combustion products. However, working in heat and smoke still requires skilled and experienced firefighters. Moreover, equipment in present use does little to overcome the visibility loss from the smoke of a fire. It is the limited visibility brought about by a fire which causes manual suppression the greatest hardship. The lack of visibility makes all firefighter actions more difficult, and this often includes locating the fire. Minimizing the distance that is traveled by firefighters in untenable conditions will result in a more rapid and effective fire attack.

3.3 THE BUILDING

When a fire department quickly extinguishes a challenging building fire, the firefighters usually take credit for making a "good stop". Often the building deserves much of the credit. Likewise, when a fire gets away from a department, the building deserves some of the blame. The likelihood of quick extinguishment will differ for various fires of similar size at the time the first fire apparatus arrives. The change in impact is brought about by the building and the location of the fire within the building.

Consider the two building designs in Figure 3. With which layout would a fire department have greater chance of in extinguishing the fire shown? Most any firefighter would rather run a hose line through design 1. Figure 3 is an extreme example, but it clearly makes the point of a building's potential to influence a fire attack. Therfore, building circulation features will influence manual suppression.

A building's influence on firefighters is similar to a building's influence on evacuating occupants. Locating proper paths can be a problem for both firefighters and occupants. However, firefighters do not have the occupants