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Residential sprinklers: the facts, the costs, and the political context

Prior to his departure IFE Chairman Peter Holland CBE OStJ QFSM FIFireE (Life) issued a challenge to produce a white paper for discussion and debate across the IFE. In response, Deputy Chief David A Greene MIFireE, USA Branch, considers the benefits of residential sprinklers

Fire continues to be a deadly risk to residents in the United States of America. In fact, in the industrialised world, the United States has one of the highest fire death rates with nearly 30 deaths per million persons (Ruegg & Fuller, 1985). Other industrialised countries have experienced 15 deaths per million people and as low as ten deaths per million people in countries such as Austria, Germany, and Switzerland. Ruegg and Fuller (1985) also indicate that the second most frequent cause of death in the home in the United States is fire.

Sprinkler systems have long been effective at saving lives and protecting property in commercial and institutional buildings. However, over the last few decades, residential sprinkler systems have become both supported by fire and life safety officials and opposed by homebuilders, developers, and many homeowners.

Costs and Benefits

The facts are straight-forward: the costs and benefits can be closely estimated, and the political context surrounding this issue is applicable to jurisdictions throughout the country.

Fire and life safety advocates continually strive to save lives and protect property. Many use enforcement by imposing penalties among those that violate fire and life safety codes. Others may use education by attempting to change unsafe behaviours through instruction. Emergency response involves reactively attempting to mitigate the problem after it, a fire, has occurred. Where emergency response serves as the last line of defence, engineering is likely the first. Engineering involves designing buildings and their components to protect the lives of occupants. One recent example is kitchen stoves which are designed with a pressure mechanism in the mat that lies in front of the stove. If someone is not standing on the mat and depressing the pressure mechanism, the stove will turn off. This prevents ignition of combustible cooking materials due to an unattended stove, which is a very common cause of residential fires. Another simpler example includes building codes which require assembly occupancies that have doors that swing outward. This is engineered into the building to allow for a more rapid egress for occupants in the event a fire occurs.

Engineering can also include sprinkler systems which are designed to confine or extinguish fires without outside assistance. Residential sprinkler systems did not evolve simultaneously with commercial and institutional sprinkler systems. However, residential construction and content compositions have changed radically over the last 20 years. Hardwood construction and nails to form joints have given way to lightweight construction and glue to form joints. Moreover, the importance of energy efficiency has led to homes that are better insulated from the outside environment and are designed to better maintain the interior environment. Additionally, contents have moved away from natural products, from cotton to synthetics, such as polypropylene and polyethylene. This results in fires that release greater heat levels under construction and fail more quickly after being exposed to fire.

Almost everyone is a proponent for smoke detectors in the home. These devices allow for quick detection of the presence of a fire and allow for rapid response by the occupants. However, as Kay and Baker (2000) illustrate, smoke detectors do not protect those who cannot easily escape without assistance, such as the elderly, children, the disabled, and the intoxicated. Even when homes are equipped with smoke detectors, they may be disconnected, disabled or inoperative (Diekman, Ballesteros, & Ahrens, 2012). Moreover, it is estimated that eight million Americans have difficulty hearing, which makes conventional smoke detectors unreliable for this segment of the population (Diekman, Ballesteros, & Ahrens, 2012).

Protection Measures

Residential sprinkler systems are designed to protect the occupants during their egress or confine the fire to the room of origin, which benefits those who are unable to escape. This prevents life threatening conditions in several different ways. Kung (1976) outlines that sprinkler systems are capable of cooling the combustion products, stopping the generation of combustible vapours by cooling burning fuels, and wetting adjacent combustible materials to prevent fire spread.

In tests, Kung (1976) found that convective heat flux dropped from 12,000 Btu/min to 2,900 Btu/min in 30 seconds after sprinkler initiation in a small compartment fire. There was also a drop in gas temperature from 450°F to 100°F in three minutes of sprinkler operation. There is also a marked decrease in carbon monoxide concentrations after sprinkler initiation (Kung, 1976). This is critical to emphasise as many fire victims are killed by inhalation of the smoke and by products of fire, such as carbon monoxide, rather than by thermal burns.

The main toxic hazards during a residential compartment are carbon monoxide, hydrogen cyanide, deficient oxygen levels, and hydrogen chloride (Yves, 2002). The evolution of these gases is as a result of the incomplete burning of the hydrocarbon based materials that are involved. Nystedt (2001) agrees that the most common cause of death in residential fires is carbon monoxide intoxication. Yves (2002) notes that occupants can minimise their exposure by crawling as close to the floor as possible as heat will cause these gases to become buoyant. Li, Chen, and Li (2011) agree with Kung and state that the volumetric flow rate decreases under sprinkler spray. This means that smoke will more slowly fill the compartment after the sprinkler system has begun operation.

While there are dangers of being exposed to the toxic by-products of combustion, there are also dangers associated with ventilating a compartment fire. For example, an under-ventilated fire will be oxygen deprived and may contain up to ten times more toxicants than a free-burning compartment fire (Hwang, Lock, Bundry, Johnsson, & Ko, 2011). However, while opening a window to ventilate an under-ventilated fire may improve air quality, it will also likely increase heat release rate and intensify the fire. As Thomas and Bullen (1979) note, increasing ventilation will increase burning rate, while the converse is also true. They note that the solution is to cool the fire at the same time it is ventilated. Beyler and Cooper (2001) concur that smoke and heat venting has no effect on sprinkler performance, nor does it delay sprinkler reaction times. Sprinkler systems serve to both improve air quality and decrease heat release rate.

Flashover Protection

Another life threatening condition that sprinklers can protect occupants from is flashover.

Flashover occurs when all available fuels become involved and the fire is burning at its maximum potential (Songyang, Zong, Chen, Wei, & Liao, 2009). This is accompanied by temperatures between 700 and 1,200°F. As Songyang, et al (2009) illustrate, the fuels that are available in today's fires have a much higher heat release rate. In their study, they found that a 500mm by 250mm by 250mm block of wood consisted of a total fuel magnitude of 3,050 grams. After igniting the wood, flashover occurred in 420 seconds. A smaller 1,905 gram polyethylene sample caused flashover in 530 seconds. The polyethylene sample represents 62 per cent of the wood sample mass but only yields a 20 per cent slower flashover time. This illustrates that synthetics and hydrocarbon based plastics will cause a flashover more quickly than wood and other natural products.

Firefighters are trained to understand that a flashover signals the end of search and rescue efforts as an unprotected person cannot survive post-flashover conditions. Firefighters are also trained on the warning signs of an impending flashover as it will even cause the failure of the heavy personal protective equipment they wear within seconds of exposure. The aforementioned energy efficient properties of today's buildings have also had an effect on this type of fire behaviour. Because buildings are designed to hold heat and cool air better as a means of comfort, the heat from fires is being better contained also. This increases the chances of a flashover occurring.

Sprinklers are designed to cool the fire and prevent flashover. This offers the best chance for occupants being rescued or escaping. There are two main types of sprinkler systems available for residential applications. The standalone system uses a dedicated water supply that is not shared by any other water using application. The multi-purpose system uses the regular domestic water supply to the residence. These are often equipped with backflow preventers which insure the domestic water supply is not contaminated by the stagnant water in the sprinkler system (Brown, 2005).

Reducing Water Damage

Residential sprinklers are generally designed to protect an area no larger than about 12ft by 12ft and use between 13 and 18 gallons per minute (Bill, Hsiang-Cheng, Anderson, & Ferron, 2002). These low flow rates are sustainable from nearly every available domestic water supply. Given the layout of most homes, each room could be protected by only one or two sprinkler heads. Additionally, Melinek (1993b) found that in multi-storey buildings, sprinklers have a more significant impact on reducing average property loss than in single story buildings. This is no doubt due to the effects it has on preventing vertical fire spread. These effects would also benefit persons trapped on floors above ground level. Nystedt (2001) notes that fatal fires typically originate in bedrooms, kitchens, or living rooms and their causes are typically smoking, electrical malfunctions, or misuse of heating devices. Melinek (1993a) suggests that installing sprinkler heads in these rooms alone could still provide an increased level of protection above having no system installed.

Nystedt (2001) found that in Sweden, there are very few residential sprinkler systems despite the fact that United States investigations suggest the death rate could be lowered by 80 per cent with their use. Low incidences of freezing, monitoring of sprinkler systems, and automatic calls to fire departments have also reduced the chance of fires in sprinkled buildings becoming large in Australia when compared to the United Kingdom and the United States (Melinek, 1993b). Melinek (1993a) notes in an evaluation of 73 fatal fires that residential sprinkler systems can reduce fire deaths by 66 per cent and 45 per cent of injuries.

Some believe that residential sprinkler systems are not designed to extinguish fires but rather only to confine them until the fire department arrives (Marvin, 1993). However, there is data to suggest a 90 per cent reduction in fire deaths and 95 per cent reduction in injuries where residential sprinkler systems have extinguished or controlled fires while giving an internal alarm (Melinek, 1993a). Butry, Brown and Fuller (2007) agree, citing a study from 2002 to 2005 which notes that houses equipped with both smoke detectors and fire sprinkler systems experienced 100 per cent fewer civilian fatalities, 57 per cent fewer injuries, and 32 per cent less property loss when compared to houses equipped with only smoke detectors.

Diekman, Ballesteros, and Ahrens (2012) agree, noting that during a study between 2003 and 2007, an 83 per cent lower death rate per 1,000 people occurred in homes with residential sprinkler systems versus those unprotected. Butry (2012) also agrees, noting that there is strong evidence that suggests residential fire sprinklers protect occupants in one and two-family dwellings from fatalities.

Protecting Firefighters

Butry (2012) also notes that sprinkler systems and smoke detector combinations are of more value and offer greater protection to older and less mobile populations. This will be paramount for the future as the size of the older population grows. In smaller communities throughout the United States, residential sprinkler systems become even more important. Between 2004 and 2008, rural fire deaths were twice the national average. This is likely due to a lack of working smoke alarms, insufficient staffing, equipment, or training, and prevention programmes in the fire department. These areas often have delayed responses due to staffing by volunteers, who must travel to the station to pick up apparatus, higher distances that must often be travelled to reach the fire scene, and lack of access to trauma centres which can manage burns and smoke inhalation (Diekman, et al, 2012).

There is also data that refutes Marvin's claims that sprinkler systems are only designed to confine fires until the fire department arrives. As Routley, Jennings and Chubb (1991) found in their study of the Meridian Bank Building fire in Philadelphia, Pennsylvania, a fire destroyed eight floors of a high rise office building and led to the deaths of three Philadelphia firefighters. During the fire, interior operations were abandoned and an exterior fire fight followed. It was thought that since floors 22 through 28 had been consumed by fire that the building might collapse. However, the fire burned to the 30th floor, which was the first fully sprinkled above the floor of ignition, where ten sprinkler heads extinguished the fire. Sprinkler proponents often point to this fire to demonstrate the power of sprinkler systems. In this case, ten sprinkler heads did what 12 alarms of resources and over 300 firefighters could not, and extinguished a fire that many thought would bring down a 38 storey building. Additionally, Butry (2012) notes that sprinkler systems protect firefighters from injuries as well.

Resistance

Despite the overwhelming evidence supporting the safety value of sprinkler systems, there is significant resistance to their universal installation. According to the National Association of Home Builders (NAHB), politics are one of many barriers preventing acceptance of residential sprinkler systems (NAHB, 1995).

There is a significant cost associated with building homes protected by residential sprinkler systems. The costs can be even higher if the system is to be retro-fitted into an existing home.

Fuller (1991) notes that homeowners typically elect not to install sprinkler systems because of the high purchase and installation costs. When pressed for safety, homebuilders prefer to use fire resistive construction in lieu of installing sprinkler systems. However, fire resistive construction only reduces the risk of structural failure or spread beyond the compartment of origin. Since 50 per cent of fire deaths occur in fires confined to the room of origin, sprinklers can provide protection that fire resistive construction cannot (Melinek, 1993b).

Ruegg and Fuller (1985) state that the homeowner and homebuilder must consider the cost-performance trade-off between sprinklers and fire resistive construction. Marvin (1993) reiterates that the issue of cost effectiveness simply prevents sprinkler installation in many cases, as the price for a sprinkler system is unjustifiably high when compared to the value of the building it is designed to protect.

However, a study from Scottsdale, Arizona examined 15 years of data and compared fires in homes equipped with sprinkler systems against those without the systems. This study found that property loss was a mere five per cent of the losses in residences not protected by sprinkler systems. A 12 year study in Prince George's County, Maryland found that sprinkler system houses sustained only one per cent of the damage in homes not equipped with sprinkler systems (Brown, 2005). However, the costs savings in limited property damage did not come with a price of only sprinkler system installation.

Systems with backflow preventers have to be inspected annually, and Butry (2007) found this to only be economical when the inspection charge was less than $100 annually. Brown (2005) indicates that professional inspection is a significant maintenance cost and is estimated at between $100 and $200 annually. Ford (1997) notes that although initial costs of installation are high when sprinkler systems are new to a community, market influences can cause the costs to drop significantly. In the Scottsdale, Arizona study, sprinklers were around $1.14 per square foot when the ordinance was first enacted. However, the price is now about $0.59 per square foot due to market competition (Ford, 1997).

Dispelling Myths

Many homebuilders and owners are worried by myths that sprinklers will activate unintentionally and cause extensive water damage. However, Kay and Baker (2000) note that sprinklers rarely activate accidentally and only operate in rooms where fire is located. Diekman, et al (2012) rejects this misconception also. They note that when one sprinkler activates, the system does not activate all sprinkler heads throughout the home. In fact, they cite that in 97 per cent of home fires, only one or two sprinklers activate. This translates to a much lower volume of water than firefighters use to extinguish the fire. Fire department hose streams generate more water damage than a properly installed sprinkler system generates (Marvin, 1993). Kay and Baker (2000) agree and note that 30 gallons per minute of water flow will cause much less property damage than the 300 gallons per minute caused by fire hoses.

Butry (2007) indicates that sprinkler systems have very small rates of accidental activation. Accidental activations due to manufacturing defects occurred in only one in 16,000,000 sprinkler heads. Overall, sprinkler head accidental discharge has been reduced to less than one in one million per year. However, sprinkler heads may require significant protection against physical contact in certain areas (Head, 1995). This could also aid in improving the aesthetics in a residence. Fuller (1991) notes that some find residential sprinklers unattractive.

Recessing the sprinkler heads would make them both inconspicuous and protected from physical damage and the potential for accidental discharge. Ruegg and Fuller (1985) reiterate that the decision to invest in a residential sprinkler system should be the decision of the homeowner; however, they note that this decision could be influenced by tax code, zoning provisions, and local, state and federal governments.

Some municipal governments have offered financial incentives for sprinkler system installation. Moreover, installation of a sprinkler system could be financed by the reduction in insurance premiums over several years (Marvin, 1993). Kay and Baker (2000) agree and indicate that installation costs for a new house can be eventually offset by insurance premium reductions. Butry, et al (2007) note that homeowners with comprehensive sprinkler coverage see an eight per cent reduction in their homeowner insurance premium. Installation in only living and dining rooms could also be a more cost effective approach than installation throughout the entire home (Melinek, 1993a).

Still, outrageous claims have been made that suggest mandating sprinkler use will increase property values to the point of no return within the community. The National Fire Protection Association (NFPA) conducted a study over a wide geographic area that contained various income levels and housing compositions comparing municipalities with and without sprinkler ordinances. They found that housing development is not impeded by fire sprinkler requirements and stress the life-saving potential (Anonymous, 2009). However, using the value of a life in cost benefit analysis is difficult. Brannon (2004) notes that placing a value on human life is both unpleasant and necessary. He also notes that because societal resources are limited, there is only so much that can be spent on health and safety improvements. Using the law of diminishing returns, investment of capital will directly cause a reduction in risks and death rates. However, a point would be reached where continued investment does not result in further reduction (Bromann, 2008). This makes the financial calculations for investment and quantifying the value of a human life controversial.

Cost of Life

The Department of Transportation uses a value of $3 million while the Environmental Protection Agency uses a mean value of $6.3 million. Mozrek and Taylor (2002) estimate the value to be between $2 million and $3 million. Leeth and Ruser (2003) assign a value between $2.6 million and $4.7 million. The mean average of these estimations translates to a human life being valued at approximately $3.86 million.

Butry, et al (2007), Brown (2005), Melinek (1993) and Butry (2009) have all performed extensive cost benefit analysis using the various inputs described above. The studies serve to evaluate anticipated benefits as reduced risk of death and injury, reduced risk of direct property loss, reduced home insurance premiums, and reduced risk of indirect costs against costs of the sprinkler system, installation, and maintenance. The calculations of benefits and costs are discounted to an expected present value of net benefits (Butry, 2009). Butry (2009) found that the present value of net benefits ranged from $794 to $5,851 depending on the type of home being evaluated. The colonial-style home had the lowest range where the townhouse and ranch-style homes had progressively higher ranges.

Melinek (1993) also notes that residential sprinkler systems have a positive present net benefit when considering the reduction in life risks; however, when disregarding the life risks it is suggested that residential sprinkler systems may be uneconomical. However, the literature is based upon the assumption that residential sprinkler systems are designed primarily to save lives. To calculate their value while ignoring their primary purpose is counterintuitive.

Installation Costs

One concern that these researchers have largely addressed is fluctuations in the costs of sprinkler system purchase and installation. Brown (2005) notes that even with a 100 per cent mark-up on materials, which is a maximum of $3,144.38, the costs of a residential sprinkler system fall below the mean average of present value of net benefits for all three types of homes examined by Butry (2009). Butry, et al (2007) examined the use of a multi-purpose residential sprinkler system. This type of system is cheaper, as it does not require a back flow preventer which involves annual inspections with associated costs. Even with a 50 per cent mark-up on purchase and installation costs, the net present value was calculated at $2,919.20 in a colonial style home, $3,099.11 in a townhouse style home, and $4,165.62 in a ranch-style home. Even at 100 per cent mark-up, all three styles of homes still yielded a positive present value of net benefits.

The extant literature indicates that not only do residential sprinkler systems provide for increased safety for occupants, protect firefighters, and reduce injuries and property damage, but they are also an economically wise investment. The literature also refutes earlier studies that suggest residential sprinkler systems are uneconomical. Although it is difficult to place a specific value on a loved one's life, the decision to install a residential sprinkler system must consider a number of factors.

As many of the authors in this literature review have outlined, homeowners ultimately bear the responsibility of weighing the cost of their lives and the lives of their families against the installation and maintenance costs associated with residential sprinkler systems. As Bromann (2008) outlines, the homeowner must balance artistic creativity versus safety features and cost versus safety. This balance is delicate and requires that homeowners be fully informed on both sides of the argument.

The literature also shows where government involvement by mandating residential sprinkler system use can also reduce the overall cost through market competition. Costs lowered by market competition would ultimately increase the present value of net benefits in every home. This allows more people easier and lower cost access to this system which is quite literally the difference between life and death.

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