Chapter 11
Active Fire Protection Systems for Residential Applications

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Abstract Residential sprinkler systems and associated design and installation standards were developed in the USA during the 1970s and 1980s. In contrast to traditional automatic sprinkler systems, the objective is to provide improved protection against injury and life loss rather than property protection. Field experience from USA indicate that the death rate is in the order of 90% lower where sprinklers and hardwired smoke alarms are present. Water mist fire protection systems can provide similar protection to residential sprinklers, using lower discharge densities. There are recognized fire test procedures as well as design and installation standards, but the market share is currently relatively low. Fixed-installed or mobile pre-engineered fire protection systems may also result in reduced water flow rates, as they are typically activated by a smoke and heat, or flame detector, which result in earlier activation. The systems are intended to be used as an alternative, or complement, to residential sprinklers for a particular part or parts of a dwelling. Many fires start in the kitchen in connection with cooking on the stove. A stove guard is a technical device that monitors the stove. When there is a risk of fire, it alarms and disconnects the power supply to the stove.

Keywords Residential sprinkler systems · Water mist systems · Stove guards · Residential fires · Kitchen fires

1 Introduction

Automatic fire protection systems require, per definition, no human intervention to operate and the most common type of system in residential area applications is probably residential sprinkler systems. Automatic sprinklers are located at ceiling level and are connected to a water source, most commonly the public water main. The sprinklers operate by the heat from the fire to prevent flashover (total involvement) in the room of fire origin and thereby give residents the time to safely escape and the fire department time to respond. Water mist fire protection systems can

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provide similar protection to residential sprinklers, using lower discharge densities. Approved automatic nozzles are available in the marketplace.

Fixed-installed or mobile pre-engineered systems may also result in reduced water flow rates when compared to a traditional residential sprinkler or even a traditional water mist system, making them suitable where the water supply or storage is limited. Typical applications include care homes and permanent or temporary accommodation for elderly, social housing, or simply private dwellings with extensions. The systems are typically activated by a smoke and heat, or flame detector, which result in earlier activation compared to residential sprinklers.

Many fires start in the kitchen in connection with cooking on the stove. A stove guard is a technical device that monitors the stove. When there is a risk of fire, it alarms and/or disconnects the power supply to the stove. The device can have detectors that respond to smoke, heat, movement, or a combination of these. The detector unit may be integrated in the cooker or it can be installed afterwards under the hood or on the wall behind the stove.

This chapter describes these technologies, installation requirements, test procedures as well as any field experience and studies.

2 Residential Sprinkler Systems

This section describes the background and development of residential sprinklers, how systems are designed and installed, the adoption and use, and field experience and summarizes some of the studies that have been conducted.

2.1 The Background and Development of Residential Sprinklers

Automatic sprinkler systems as known today have been used since the late 1800s. The systems were primarily developed for property protection of industrial and commercial properties. In 1973, the National Commission on Fire Prevention and Control issued the report America Burning [1]. The report evaluates the fire loss in the USA and provides recommendations to reduce loss and increase safety of citizens and fire service personnel. Among 90 recommendations were a proposal that the US Fire Administration (USFA) should support the development of the necessary technology for improved automatic extinguishing systems for dwellings.

At the same time that the America Burning report was issued, the National Fire Protection Association (NFPA) initiated the development of NFPA 13D, which when released in its first edition in 1975 had the title "Installation of Sprinkler Systems in One- and Two-family Dwellings and Manufactured Homes." In contrast to the NFPA 13 standard on traditional automatic sprinkler systems, the objective was life safety rather than property protection [2].

Between 1975 and 1980, several research projects and field tests were conducted [3, 4]. A crucial question during the development work was that the sprinkler system needed to be affordable and that it could function with the existing water supply of a building [5]. Based on the outcome from the testing and development work, NFPA 13D was rewritten and published in its second edition in 1980. It was not until 1981 that the first commercial residential sprinklers were approved [6]. A residential sprinkler is characterized by early activation and a high, flat, and wide water distribution pattern. The sprinkler must be able to distribute water over sofas, drapes, curtains, and the like in the outer edges of a room and prevent the spread of fire along walls and ceilings.

NFPA 13D had a major impact and began also to be applied in apartment buildings and NFPA realized that the time was ready for a new, national standard for residential sprinklers in apartment buildings and other types of housing. The result was NFPA 13R (R stands for Residential) published in 1989 where the sprinkler concept was expanded to include residential buildings up to and including four stories in height. The concept also included hotels, motels, and certain types of care homes.

2.2 Installation Requirements in NFPA 13D and 13R

The overall performance objective of NFPA 13D [7], "Standard for Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes," is to provide improved protection against injury and life loss. A sprinkler system shall be designed and installed to the standard to prevent flashover (total involvement) in the room of fire origin and thereby give residents the time to safely escape and the fire department time to respond. Sprinklers are only required to be installed in living areas. Sprinklers in smaller bathrooms or closets, pantries, garages, or carports, attached open structures, attics, and other concealed non-living spaces are not required. The sprinkler system shall be hydraulically designed to provide at least the water flow for a minimum discharge density of 2.05 mm/min or the sprinkler listing, whichever is greater, to all the sprinklers within a compartment, up to a maximum of two sprinklers.

Where stored water is used as the sole supply of water, the standard requires that the quantity should correspond to at least 10 min of discharge. For a single-storey building that is less than 185 m^2 in area, the quantity of water can be reduced to equal a 7 min discharge.

Two common types of fire sprinkler layouts are acceptable under NFPA 13D, a regular stand-alone and a multipurpose system. A stand-alone sprinkler system serves only the fire sprinklers. A multipurpose system combines the domestic cold-water system with the residential sprinkler system. This solution could provide increased reliability as any impairment to the water supply would be more rapidly recognized. If correctly designed, it may also eliminate the need for any back flow prevention device as water is not stagnant in the piping.

NFPA 13R [8], "Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies," covers the design and installation of automatic sprinkler systems in residential occupancies up to and including four stories in height in buildings not exceeding 18 m. The intent of the standard is to provide a sprinkler system for improved protection against injury, life loss, and property damage in multi-family dwellings.

Sprinklers should be installed throughout a building, but are permitted to be omitted in smaller bathrooms or clothes closets, linen closets, and pantries within dwelling units. In addition, sprinklers are not required for many exterior attached open structures such as stairs, carports and certain balconies, or in attics, elevator machine rooms, and similar spaces that are not intended for living purposes or storage. The sprinkler system shall be hydraulically designed to provide at least the water flow for a minimum discharge density of 2.05 mm/min or the sprinkler listing, whichever is greater, to all the sprinklers within a compartment, up to a maximum of four sprinklers. The water supply shall be capable of supplying the system demand for at least 30 min.

Where buildings are greater than four stories in height, the residential parts of such buildings should be protected with residential or quick-response sprinklers in accordance with NFPA 13. There were four main reasons why four stories were chosen as the limit [9]:

1. The concept was intended for multi-dwelling houses with a wooden frame, the use of which is limited to a maximum of four floors in most building regulations.
2. The rescue service's efforts in the event of fire are an important part of the concept and in lower buildings they use extendable ladders and need not to rely on machine ladders.
3. In higher buildings, more people are at risk of being exposed to a fire and it was judged that buildings over four floors require a sprinkler concept with the higher reliability associated with the recommendations in NFPA 13.
4. Buildings with more than four floors normally require riser pipes or indoor fire hydrants with a water requirement sufficient to supply a sprinkler system in accordance with NFPA 13.

2.3 Residential Sprinkler Requirements in the USA

Currently (2020), all US model building codes contain requirements for fire sprinklers to be installed in all new, one- and two-family homes and all multifamily residences [10]. The International Residential Code (IRC) is a model code used as a basis for the locally adopted regulations for the construction of single-family homes in almost all jurisdictions. As a model code, the IRC requires sprinklers to be installed in all new homes. However, each state or local jurisdiction can reject specific parts of the model code for their particular jurisdiction during their adoption process, and most reject the sprinkler requirement. The only states or regions that currently require sprinklers in new, one- and two-family homes are California, Maryland, and the District of Columbia [10].

Home and building industry groups have actively organized efforts to prevent sprinkler mandates in at least 25 states. Several other states have agreed to let local jurisdictions decide whether to adopt the sprinkler requirement, and many have. For example, in Illinois, more than 100 communities have adopted requirements for sprinklers [10].

Several organizations advocate sprinkler protection for all new homes and provide information about residential sprinkler systems for the public, like the Home Fire Sprinkler Coalition, the National Fire Protection Association, and the International Residential Code Fire Sprinkler Coalition.

2.4 Adoption and Use of Residential Sprinklers Outside of USA

Residential sprinklers gradually started to be used outside of USA in the late 1990s. The adoption and use in some European countries are discussed below.

The Swedish Fire Protection Association published design and installation recommendations for residential sprinkler systems in 1997 [11]. These recommendations were to a large extent based on NFPA 13D and 13R. The awareness and use of residential sprinklers were enhanced in Sweden during the beginning of 2000s as a result of the national research project, “Residential sprinklers save lives”. The project resulted in several sprinkler model installations, a handbook [12], revised design and installation recommendations [13], and a video illustrating the performance of a residential sprinkler [14]. Figure 11.1 shows two photos from the video. In 2009, a Nordic standard, INSTA 900-1 [15], was published that was implemented in Sweden and Norway as a national standard. The second part of the standard, INSTA 900-2 [16], covers fire test procedures for residential sprinklers and was adopted from UL 1626 [17]. The third part, INSTA 900-3 [18], contains fire test procedures for water mist fire protection nozzles. In 2019, almost 40,000 residential sprinklers were installed in Sweden, which corresponded to about 5% of all installed sprinklers [19].

Since July 2010, the Norwegian building code has required sprinklers in almost all new buildings, with the exception of single-family houses and some small buildings in which people do not sleep. This opened a market for residential sprinklers installed per INSTA 900-1. In 2019, approximately 190,000 residential sprinklers were installed in Norway, which corresponded to almost 24% of all installed sprinklers. The water mist market totalled 29,213 nozzles and 73% of them were residential nozzles [20].

Fig. 11.1 The performance of a residential sprinkler (left) with limited fire damage as compared to the fire damage caused by flashover (right). (Photos from the video "Residential sprinkler saves lives" from 2001 [14])

In the United Kingdom, British Standard BS 9251:2014 [21] gives recommendations for the design, installation, maintenance, and testing of fire sprinkler systems in domestic and residential occupancies. This British Standard superseded BS 9251:2005. A series of regulatory changes have led to dramatic growth in the market. First, the Rose Park care home fire in Glasgow in 2004, which killed 14 elderly residents, led Scotland a year later to mandate the installation of sprinklers in all new care homes and in apartment buildings higher than 18 m. In 2007, England and Wales introduced requirements to fit sprinklers in new built apartment buildings higher than 30 m, along with a number of incentives to fit sprinklers in new three-storey and four-storey houses (a four-storey house needs sprinklers or a second staircase). The publication in 2011 of BS 9991 [22], a code of practice for fire safety in residential buildings, introduced further incentives for sprinklers in apartments in the UK. In 2016, Wales became the first country to require sprinklers in all new housing. The Grenfell Tower disaster in London in 2017 killed 72 residents and led many local government authorities voluntarily to fit sprinklers in existing high-rise social housing. As part of its response to this disaster, late in 2020 the government introduced a requirement to fit sprinklers in new built apartment buildings in England higher than 11 m [23]. Meanwhile, the Scottish government announced that in 2021 it would introduce requirements to fit sprinklers in all new built flats and shared multi-occupied residential buildings [24]. The British residential sprinkler market in 2020 is estimated to be over 500,000 sprinklers and expected to grow further with the new requirements.

Elsewhere in Europe, there are regulatory requirements to fit sprinklers in large care homes in Denmark and in most new care homes in Finland. In Finland, the requirements were retrospective and led to over half of all existing care homes being retrofitted with sprinklers. While their markets are still small, some care homes have been protected with residential sprinklers in Belgium, France, Germany, and The Netherlands. In 2020, an increasing number of projects, including for apartment buildings, were reported to be specifying sprinklers in France and The Netherlands. Looking ahead, the French government is encouraging the use of wood in residential buildings and this is expected to lead to greater use of residential sprinklers in France.

In 2018, a European standard on the design, installation, and maintenance of residential sprinkler systems, EN 16925:2018 [25], was published. The standard includes three system types, 1, 2, and 3, dependent on the application. System type 1 is intended to be used in one- or two-family dwellings and requires the lowest discharge densities and fewest number of sprinklers in the design. System type 3, intended for apartment buildings, care homes as well as small hotels and hostels, requires more stringent design criteria. Some countries may have a national informative annex with guidance on the minimum design discharge density and on the number of design sprinklers for each system type. In 2020, a European standard for testing of residential sprinklers, EN 12259-14:2020, was published [26]. The fire tests of this standard are identical with those of UL 1626 [17].

2.5 Residential Sprinkler Field Experience

Several communities in USA have documented field experience with residential sprinklers. Given below are two examples.

In 1992, Prince George's County in Maryland introduced a regulation requiring the installation of residential sprinklers in all new single- and multi-family homes [27]. Since 1992, more than 45,285 building permits have been granted for single- and multi-dwelling houses. For 15 years, from 1992 to 2007, a total of 13,494 fires occurred in single-family houses or townhouses. At 245 of these fires, residential sprinklers were installed. No person perished in the fires and only six cases of personal injury have been reported. In the 13,249 fires that occurred in homes without sprinklers, a total of 101 people lost their lives and 328 were injured. Home fires accounted for a total of 89% of all Prince George's County fire fatalities during this time. The average direct fire damage cost for a fire in a single-family house or townhouse without sprinklers was $9983, compared to $4883 if sprinklers were installed. The fire damage cost was thus about half as high. The average direct fire damage cost for a fire (without sprinklers) that resulted in fatalities was $49,503, i.e. just over 10 times higher than if sprinklers were installed.

Scottsdale, Arizona, is a suburb of Phoenix with approximately 258,000 residents (2019). The city has long experience of sprinkler systems [28–30]. In January 1986, sprinkler requirements were introduced in all types of new buildings, including single-family dwellings. Ten years later, on January 1, 1996, sprinklers were installed in 19,649, or 35% of all single-family homes and in 13,938, or 49% of all multi-family homes in Scottsdale. A further 5 years later, on January 1, 2001, the number of single-family dwellings with sprinklers had increased to 39,258 (51%) and the number of multi-dwelling houses with sprinklers to 19,422 (57%), i.e. almost 60,000 dwellings. In a total of 97 fires, it is estimated that 13 lives were saved by residential sprinklers. The statistics also show a significant reduction in the average fire damage cost with residential sprinklers.

2.6 Residential Sprinkler Studies

Ahrens [31] has analyzed data from the National Fire Incident Reporting System (NFIRS) in the USA regarding sprinkler reliability and efficiency. The analysis is based on data from the years 2010 to 2014. Some form of sprinkler was installed at 49,840 of all fires in buildings that were reported. This represented an average of 10% of all reported fires. Sprinklers were mostly found in institutional buildings such as nursing homes, hospitals, and prisons. Most fires and deaths occurred in residential buildings, but sprinklers were found in only 8% of the residential fires. Sprinklers operated and controlled the fire in 91% of the residential fires where the fire was large enough to activate the sprinklers. Only one sprinkler operated in 88% of these fires and in 98% of the fires, five or fewer sprinklers operated. Compared to reported residential fires with no smoke alarms or any sprinklers, the death rate per 1000 reported fires was 88% lower where hardwired smoke alarms and any automatic extinguishing systems (AES) were present and 90% lower where sprinklers and hardwired smoke alarms were present. When sprinklers were present, the average loss per fire was less than half the average compared to properties with no AES. In three out of five (62%) of fires in which sprinklers failed to operate, the system was shut off.

Optimal Economics Ltd. [32] provides a detailed analysis of data on fires in premises in the UK, during the years 2011 to 2016, where sprinkler systems were installed. The analysis included 2294 incidents of which 1725 (75%) were in non-residential buildings and 414 (18%) in dwellings. In total, sprinkler systems operated in 945 of the 2294 incidents. Of these, 276 (29.2%) of the cases were in dwellings and 42 (4.4%) in other types of residential buildings. Sprinklers in dwellings controlled or extinguished the fire in 99.5% of the cases and in all the other residential building fires. However, the latter performance effectiveness figure was, as mentioned, based on few incidents. Fires in dwellings where the sprinkler system operated had an average area of fire damage of under 4 m^2, as compared to approximately 18 m^2–21 m^2 for all dwelling fires in England during a similar period of time.

Gritzo et al. [33] have analyzed the contribution of fire on the total lifecycle carbon emissions of one- and two-family dwellings and the reduction to that contribution achieved with residential sprinkler systems. It is concluded that the contribution of fire to the total lifecycle carbon emissions of homes without sprinklers is between 0.4% and 3.7%. The contribution of fire risk to the total lifecycle carbon emissions of a home is reduced to 0.2% when sprinklers are used, as all large fires are eliminated. In support of this analysis, fire tests [34] were conducted to measure the reduction in the environmental impact by residential sprinklers.

Hall et al. [35] have analyzed the reduction of the cost of personal injury in fires with residential sprinklers. The hypothesis was that a fire that is reduced by residential sprinklers not only reduces the frequency of injuries, but also the severity of the personal injuries when they occurred. A calculation model was used to investigate the impact on the number of personal injuries and the cost of personal injury per 100 residential fires. Cost data were available for (a) medical costs, (b) legal and liability costs, which are usually relatively low, (c) costs associated with lost work time, and (d) pain and suffering costs. The latter tended to dominate the total cost. Sprinkler effect was estimated for total injury costs and for medical costs alone. Four types of injuries were studies; burns only, smoke inhalation only, both burns and smoke inhalation, and other injury. The main results of the study show that residential sprinklers reduce the number of injuries in the event of a residential fire by 29%, medical costs by 53%, and total costs of injuries by 41%.

Butry [36] has conducted a benefit-cost analysis to measure the expected present value net benefits (PVNB) of a residential fire sprinkler system in a newly constructed, single-family house. Three typical single-family house types were investigated. The sprinkler designs vary by installation cost and require annual maintenance, but all were designed to meet the NFPA 13D standard. The estimated benefits of fire sprinklers include reductions in the following: the risk of civilian fatalities and injuries, homeowner insurance premiums, uninsured direct property losses, and uninsured indirect costs. The results show that residential sprinkler systems not requiring expensive annual maintenance are economical.

BRE Global has undertaken a cost benefit analysis of residential sprinklers installed in the UK [37]. The study shows that residential sprinklers are cost-effective in all residential care homes for elderly people, children, and disabled people (including care homes with single bedrooms). Residential sprinklers are also cost-effective in most blocks of purpose built flats, larger blocks of converted flats, and traditional bedsit type HMOs where there are at least six bedsit units per building. Note: A house in multiple occupation (HMO) is a British English term which refers to residential properties where 'common areas' exist and are shared by more than one household.

3 Water Mist Fire Protection Systems

Water mist fire protection systems typically use less water than sprinkler systems but higher operating pressures. The fire protection performance of such systems for residential area applications has been investigated in several research projects.

In the mid-1990s, the US Fire Administration (USFA) funded two projects to explore the possibilities of using water mist systems as an alternative to residential sprinklers. Primarily, it was the opportunity to reduce the water demand that was the most interesting to investigate as there are many areas in the USA where the availability of water reduces the possibilities of using residential sprinklers. The first study [38] investigated the possibilities of using water mist for the type of fire scenarios that are relevant in residential areas. The tested systems included a low-pressure system, three different high-pressure, and a "dual-fluid" system. The latter system generated mist by air impingement as opposed to small orifices. Only two of the systems tested showed reasonably good results. For these systems, it was possible to draft preliminary installation instructions. The installation cost for these two systems was estimated and concluded higher than that for residential sprinklers, mainly due to the higher material cost. Based on the first study, USFA went on to a second study [39, 40]. The intention was, among other things, to further study the use of water mist in a residential environment, to develop a test method, and to make a recommendation for installation standards. Since the first study showed that the cost of high-pressure systems was too high, low-pressure systems were studied. These systems are likely to use plastic pipes and do not require additional piping for air or other media for the atomization of water. Additional fire tests were conducted using two commercial and two prototype nozzles. The operating pressures were between 7.7 and 11 bar. It was concluded that the level of performance was comparable to that of residential sprinklers, using lower total water flow demand. However, the higher operating pressure means that the systems cannot be connected directly to the public water supply and a pressure pump is required. Therefore, a lower reliability due to the increased number of components is expected. A calculation shows that the increased probability of malfunction may be 0.03 per year. This means that if 100 systems are used for 1 year, one can expect that three more systems will malfunction compared to residential sprinkler systems directly connected to the public water supply. Sprinkler statistics (industry) show that the malfunction of a properly sized sprinkler system is 0.02–0.03 [41], which gives an idea of the order of magnitude of the increase. The main contribution to the lower reliability is the probability that the valve required to “isolate” the pump is closed. The contribution from other components such as the pump and the pressure switch is low. Regarding nozzle clogging, practical tests show that this cannot be expected to be a problem for the nozzles used in the test series.

RISE Research Institutes of Sweden have conducted a more recent series of residential sprinkler and water mist nozzle fire tests [42] in a test compartment sized 3.66 m by 3.66 m (12 ft. by 12 ft.). The fire test source consisted of either a simulated or an authentic upholstered chair. Benchmark residential sprinkler tests were conducted using a water flow rate of 30.3 l/min. This was the minimum listed flow rate given by the manufacturer for the compartment size. Additional tests were conducted using 60.6 l/min, corresponding to the relevant design density of 4.1 mm/min in NFPA 13. The performance of several commercial, automatic low- and high-pressure water mist nozzles was determined. The flow rates of the water mist nozzles ranged from about 17 to 37 l/min. Generally, it could be concluded that the performance of these nozzles was comparable or better than the residential sprinklers using approximately half to one-quarter of the water flow rate. Figure 11.2 exemplifies the performance with the measured mean gas temperature inside the test compartment. The gas temperature was measured at eye-level (1.6 m above floor) at the centre point of each of the four quadrants of the test compartment, except for the quadrant with the fire test source. The data are for the tests with the simulated upholstered chair.

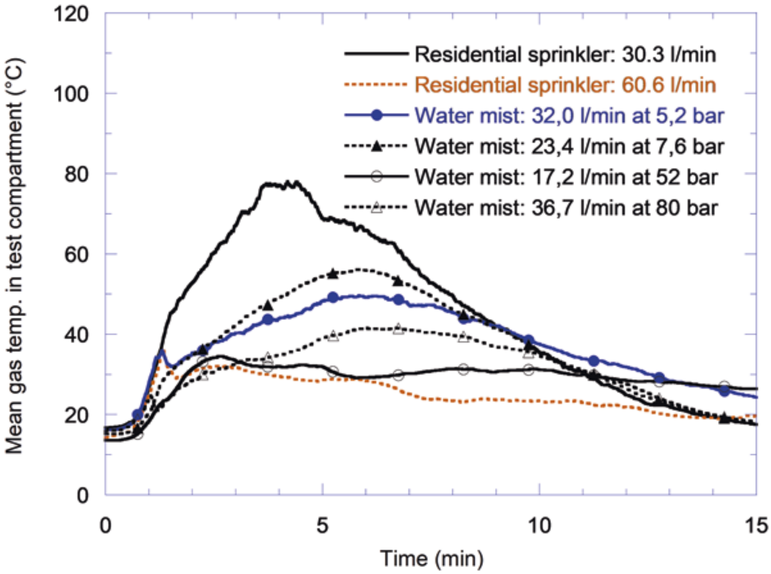

Fig. 11.2 The mean gas temperature at eye-level (1.6 m above floor) inside the fire test compartment when testing residential sprinklers and water mist fire protection system nozzles [43]

The high-pressure water mist nozzles provided the best cooling. This observation supports the assumption that smaller water droplets provide efficient gas phase cooling. The combustible foam cushion that was used for the fire test source was completely or almost completely consumed in all tests. The lowest measured mean gas temperature inside the test compartment was recorded in the test with the residential sprinkler flowing 60.6 l/min.

Underwriters Laboratories Inc. (UL) has developed a fire test procedure for automatic water mist nozzles intended for residential area applications, UL 2167 [43]. The method resembles that used for residential sprinklers; however, the application is limited to one- and two-family dwellings and manufactured homes. If a single nozzle activates during the tests, an actual system should be designed using two nozzles. If two or three nozzles activated, four nozzles should be included in the design.

British Standard BS 8458:2015 [44] provides recommendations for the design, installation, water supplies, commissioning, maintenance, and testing of water mist fire protection systems with automatic nozzles. The field of application includes systems installed in residential and domestic occupancies up to a maximum ceiling height of 5.5 m. The document primarily covers water mist fire protection systems used for life safety, but the systems may also provide property protection.

4 Pre-engineered Fixed-Installed or Mobile Area Fire Protection Systems

Pre-engineered systems are systems which have the number of nozzles and the piping calculations for the system pre-defined by the manufacturer. This results in less work and responsibility to the designer/installer to ensure that the water supply will be enough for the application. This also means that the application may be specific to a hazard, room, location, or property. Determining whether the solution is fit-for-purpose is still the responsibility of the installer. Pre-engineered systems may also result in reduced water flow rate when compared to a traditional residential sprinkler or even a traditional water mist system where the water supply has to include a safety margin for a maximum number of nozzles. This makes the systems more suitable for retrofit or temporary use, where water supply or storage is limited.

There are several pre-engineered fire protection systems in the marketplace that are either fixed-installed or mobile and are intended to be used as an alternative, or complement, to residential sprinklers for a particular part or parts of a dwelling. Typical applications include care homes and permanent or temporary accommodation for elderly, social housing, or simply private dwellings with extensions.

4.1 Fixed Pre-engineered Water Mist Systems

Fixed pre-engineered systems are primarily used as an alternative to a traditional sprinkler system (also fixed) and therefore are most frequently used to meet building code requirements. These systems are optimized to minimize the flow of water, which is usually limited in a single home, or because there is usually much less space available for a tank. The specific design flows allow for a single type of pipe diameter which has a maximum length (maximum acceptable pressure loss) for the whole installation. Given these are domestic systems intended to protect one or two dwellings, pipe lengths do not need to be significant. A multi-dwelling building would have a system on every dwelling, connected directly to the existing water drinking supply of that home as opposed to a central system with tanks and booster pumps for the exclusive use of fire fighting. Such systems must meet the same fire performance requirements of traditional sprinklers or traditional water mist systems, and the installation is intended to remain as part of the structure of the building with the intention of meeting building code requirements.

Such systems have also, more recently, been used to upgrade the fire safety of existing buildings, either to voluntarily bring them up to existing code or because occupants are found to be more vulnerable than the code at the time of construction assumed. Once again, the reduced water flow makes them easier (and less costly) to retrofit than traditional systems.

4.2 Mobile Pre-engineered Water Mist Systems

A mobile water mist unit is intended to be used as a safety-enhancement device, not to meet building code requirements. It is most frequently used for those with limited mobility or high-risk behaviour who might be a victim of a fire while intimate to the fire itself. As a result, these units are most frequently designed to cover a single room or only a limited area of a room, such as a couch, bed, or chair, where the source of the fire might take place.

A mobile system may consist of a unit containing a smaller sized water tank, a pump, a fire alarm panel, and an integrated water mist nozzle. The unit should be strategically positioned inside the room to be protected and is connected to an electric power supply. The system may be activated by a separate smoke and heat, or flame detector positioned at the ceiling or only to the area of protection (in the case of flame detector). The choice of detection method is the result of the vulnerability of the occupant and therefore the need of quick activation. The amount of water in the tank is sufficient for a care giver to respond to where the activation has occurred and may include up to 10–15 min duration. Additional nozzles, for example above specific fire hazard areas, the bed, or in adjacent rooms, can be connected to the unit if the pre-engineered design supports this functionality. Because the system will most probably wet the occupant and there is limited run time on the system, it is assumed that this system is used in applications where help can arrive in short notice. These systems, therefore, usually have an output signal facility to indicate that they have been activated so that attention of the care giver can be summoned.

The system must be positioned, installed, and maintained by an authorized installer. Periodical inspection includes a verification that the system and the nozzles are not being obstructed. These systems do not have to meet the fire performance tests of existing national and international standards used to meet building code. Performance may be assessed in a case by case basis based on the occupation and risk.

In 2007, Sweden and Norway issued a common guidance for the installation and fire testing of mobile pre-engineered water mist systems. The stated objective is that the system should provide an early alarm and control a fire such that gas temperatures and toxic gases are limited during the time required for the fire service to rescue and fight a fire. The manufacturer should verify and declare that the product meets the requirements of the guidelines and guarantee the function of the system; no approvals are issued [45].

4.3 Fire Tests and Field Experience

RISE Research Institutes of Sweden have conducted a series of residential sprinkler and automatic water mist nozzle fire tests that included a commercial pre-engineered mobile high-pressure water mist system [42]. The system was activated by a combined heat and smoke detector which provides for earlier activation compared to a frangible glass bulb used for residential sprinklers. The flow rate of 8 l/min was significantly less than that of the other systems. The performance was comparable to that of the fixed-installed automatic water mist nozzles in the study. However, the results suggest that the position of the fire test source relative to the position of the unit is a crucial factor and underlines the importance of a thoughtful positioning in practical applications.

Field experiences indicate that life has been saved by these types of systems. In a pilot project in 2012, the City of Copenhagen installed 50 mobile systems in homes with residents judged having an increased probability of fire. The project was immediately successful and an additional 220 units were purchased in 2013 and 2014. After 3 years, the project was evaluated, and it turned out that nine lives were probably saved, and the cost of fire damage was reduced [46].

Runefors and Frantzich have conducted a cost-benefit analysis of mobile pre-engineered water mist systems in Sweden [47]. The advantage of mobile systems is that they can be arranged in a room without major intervention in the home. Some of the systems are also possible to reassemble in new dwellings. If the analysis includes mobile systems for the entire elderly population, the societal benefit does not exceed the overall cost. But for particularly vulnerable groups, it is concluded that the benefit outweighs the cost of the installation. This is especially true for older people who are smokers. For this group, the measure is highly socio-economically profitable with a benefit ratio of 1.57–4.92 depending on age group and whether the system is reused in other homes or not.

5 Stove Top Protection Systems

Many fires start in the kitchen in connection with cooking on the stove. A stove guard is a technical device that monitors the stove. When there is a risk of fire, it alarms and (if no one responds) disconnects the power supply to the stove. The device can have detectors that respond to smoke, heat, movement, or a combination of these. The detector unit may be integrated in the cooker or it can be installed afterwards under the hood or on the wall behind the stove. The device is usually discreetly designed and does not require much space. In addition, a stove guard can be supplemented with a fire extinguishing module. The stove guard may be connected to the Wi-Fi and send a remote warning to the user's mobile phone, or to another receiver that is able to respond on the alarm.

All stove guards marketed in the EU and ESS must be designed and manufactured in accordance with EN 50615:2015 [48], be type tested, and CE marked. The standard divides the stove guards into three classes:

- Category A: The stove guard should be capable of extinguishing a fire. When the extinguishing agent is applied, the power supply to the stove is disconnected.

- Category B: The stove guard disconnects the power supply to the stove when there is a risk that a fire may occur.
- Category AB: The stove guard disconnects the power supply to the stove when there is a risk that a fire may occur, and it can also extinguish a possible fire.

The extinguishing ability (Category A) is tested with a pan with sunflower oil. The stove guard must detect the fire within 45 s and the fire must be extinguished without splashing oil. The fire must not reignite within 10 min. In addition, a fire in a roll of kitchen paper must be extinguished. The ability to prevent a fire from occurring (Category B) is tested with a pan with sunflower oil. The oil is heated on the highest power position and the voltage to the stove must be disconnected before the oil reaches 330 °C. Thereafter, the temperature of the oil must not exceed 350 °C during the following 10 min. A challenge for manufacturers is that the stove guard must be able to distinguish an incipient dangerous situation, for example when a pan with hot oil approaches the self-ignition temperature, from normal cooking. If the stove guard often disconnects the stove during normal operation, the user may lose confidence in the technology, which becomes an annoyance. If the stove guard does not disconnect the power supply before or when a fire occurs, an incident can in the worst case lead to a fully developed kitchen fire. Therefore, a false alarm test is also included with three pans filled with boiling water and a pan with oil. It is only when the oil gets too hot that the stove guard disconnects the power. Some stove guards therefore have several types of detectors, such as Infra-Red (IR), heat, and motion detectors as well as built-in logic to reduce the probability that the power supply is accidentally disconnected.

The most common type of stove guard in the marketplace is of Category B, although the other categories can be found in the market.

5.1 Fire Tests and Field Experience

There are some documented experiments with stove guards, but since technological development has progressed rapidly in recent years, the results are not certainly relevant to today's technology. In 2010, the fire test laboratory at SINTEF in Norway conducted tests with stove fires [49]. A total of 76 tests were performed, of which 23 were initial tests without stove guards. In addition to using different types of stoves, the plate used, the type of cookware, and the type of oil or cooking fat were varied. Seven different stove guards were tested. Based on the tests, only three stove guards could be considered to perform satisfactorily. The major challenge for them was to distinguish an incipient dangerous situation, for example when a pan with hot oil approaches the self-ignition temperature, from normal cooking. It was only one stove guard which managed to reduce the probability of false activation in combination with a high probability of reacting to an initial dangerous situation. This stove guard was the most advanced of those tested and had an IR detector to measure the infrared heat radiation, an optical flame detector, and a temperature sensor. The detector unit was also mounted directly above the cooker top, which means that the function is less affected (no shielding of the view) by the design of the pans and where they are placed on the top. Since 2010, stove guards meeting the requirements in EN 50615 are required to be installed in all new dwellings in Norway [50], but there are currently no available studies whether or not they have reduced the number of kitchen fires.

In 2011, RISE Research Institutes of Sweden tested some of the stove guards in the marketplace [51]. Since at that time there was no standardized test method, a methodology was developed. The objective was to test the stove guards in as real an environment as possible and they were judged to work if they disconnected the power supply early enough to prevent a fire or before the food developed very heavy smoke. Four different stove guards were tested and two different stoves, one with a ceramic cooker top and one with cast iron plates. A total of 74 different tests were conducted. In cases where the stove guard did not work, only one attempt was made. For the setups where the stove guard worked, the test was repeated to verify the result. In the 68 different trials where a result was obtained, the stove guard performed as intended in 33 cases and failed in 35 cases.

Runefors and Frantzich have conducted a cost-benefit analysis of the installation of stove guards in Sweden [47]. The analysis is based on the system reducing the number of fatalities and injuries in fires and a reduced need for fire service rescue efforts. Additionally, reduced property damage in the dwelling because of a lower number of fires was accounted for. From a societal perspective, it was concluded that the installation of stove guards is not cost-effective. The savings do not compensate for the cost of installing stove guards in all homes, i.e. the benefit ratio is less than 1.0. However, there are indications that it may be socioeconomically profitable to install stove guards in homes for the elderly. But the uncertainty in estimating the prevention of personal injury is quite large which would require a more nuanced analysis to be performed.

6 Summary

Residential sprinkler systems were developed in the USA during the 1970s and 1980s and have proven an efficient means of improved protection against injury and life loss. Field experience from USA indicates that the death rate is in the order of 90% lower where sprinklers and hardwired smoke alarms are present. In addition, residential sprinklers do reduce the number of injuries in the event of a residential fire, medical costs, and total costs of injuries. Other benefits include a reduction of homeowner insurance premiums, uninsured direct property losses, and uninsured indirect costs. It is estimated that about 8% of homes in the USA are equipped with residential sprinklers. Although all U.S. model building codes include sprinkler requirements for all new, one- and two-family homes, each state can reject specific parts of the adopted code for their particular jurisdiction. This is the reason why residential fire sprinklers are not required in most areas, despite the model code requirements.

Residential sprinklers gradually started to be used outside of USA in the late 1990s, particularly in the Nordic countries and in the UK. Since July 2010, the Norwegian building code has required sprinklers in almost all new buildings, apart from single-family houses and some small buildings in which people do not sleep. In 2019, approximately 190,000 residential sprinklers were installed in Norway, which corresponded to almost 24% of all installed sprinklers. In 2007, England and Wales introduced requirements to fit sprinklers in new built apartment buildings higher than 30 m, along with several incentives to fit sprinklers in new three-storey and four-storey houses. In 2016, Wales became the first country to require sprinklers in all new housing. The British residential sprinkler market in 2020 is estimated to be over 500,000 sprinklers and expected to grow further with the new, upcoming requirements.

Water mist fire protection systems can provide similar protection to residential sprinklers, using lower discharge densities. There are recognized fire test procedures as well as design and installation standards that increase the market opportunities for the systems. In Norway, residential water mist nozzles had a market share of about 10% of the residential sprinkler market in 2019. Fixed-installed or mobile pre-engineered fire protection systems may also result in reduced water flow rates, as they typically are activated by a smoke and heat, or flame detector, which result in earlier activation. The systems are intended to be used as an alternative, or complement, to residential sprinklers for a particular part or parts of a dwelling. A mobile system may consist of a unit containing a smaller-sized water tank, a pump, a fire alarm panel, and an integrated water mist nozzle. The unit should be strategically positioned inside the room to be protected and is connected to an electric power supply. Additional nozzles, for example above specific fire hazard areas, the bed, or in adjacent rooms, can be connected to the unit if the pre-engineered design supports this functionality. Document field experience is limited, but experience indicates that life has been saved by these types of systems.

Many fires start in the kitchen in connection with cooking on the stove. A stove guard is a technical device that monitors the stove. When there is a risk of fire, it alarms and disconnects the power supply to the stove. The device can have detectors that respond to smoke, heat, movement, or a combination of these. All stove guards marketed in the EU and ESS must be designed and manufactured in accordance with EN 50615:2015, be type tested, and CE marked. There are currently no available studies showing to what extent the use of stove guard has reduced the number of kitchen fires.

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