Reframing how Complex Building Code Proposals are Assessed:

The Case of Home Fire Sprinklers

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Abstract

Nationally, and internationally, model building, construction, and life safety codes and standards are developed through a consensus process of qualified stakeholders which often includes an evidence requirement to substantiate a change. These codes and standards must then be adopted at the appropriate level of government. In Massachusetts, that is through one of many Governor-appointed regulatory boards who have no duty to rely upon evidence in their legislative decisions. Through the first two research papers, this dissertation improves the evidence base related to the effectiveness and benefit-cost of home fire sprinklers, specific to Massachusetts, culminating in a policy-focused white paper (Research Paper 3) that includes a specific framework for the BBRS to utilize when deciding whether to require home fire sprinklers in newly-built one- and two-family homes. The research hypothesis is: adding MA-specific fire data to existing policy-informing models relative to mandatory sprinkler installation requirements in newly-constructed one- and two-family dwellings will result in a policy recommendation that is in favor of adopting the language of the *International Residential Code* relative to residential sprinklers.

Research Paper 1. Association between home fire sprinklers and civilian injuries and deaths in Massachusetts: 2009-2018. Rates of injuries and fatalities from structure fires in one- and two-family homes have increased over time; however, few studies have assessed the efficacy of home fire sprinklers in reducing morbidity and mortality. We utilized a comprehensive fire dataset to assess the association between home fire sprinklers and civilian injuries and deaths in single- and two-family home fires over a 10-year period. Structure fire data were extracted from the Massachusetts Fire Incident Reporting System (2009—2018) and were geocoded and connected with parcel attributes and housing and population data from the American Community Survey. Univariable and multivariable logistic regressions were used to determine the association between home fire sprinklers and odds of civilian injuries and deaths, controlling for common risk factors. A total of 13,867 structure fires were analyzed. In multivariable analysis, presence of home fire sprinklers was associated with a 60% reduction in the odds of civilian injury (OR = 0.40, 95% CI: 0.15—1.12) and 33% reduced odds of civilian death (OR = 0.67, 95% CI: 0.09—5.13) compared to homes without home fire sprinklers. Our results suggest that home fire sprinklers may reduce civilian injuries and deaths in single- and two-family homes, compared to similar homes without home fire sprinklers. Despite these reductions being independent of other risk factors evaluated, their magnitudes of reduction are subject to a wide range of uncertainty.

Research Paper 2. Benefit-cost analysis of fire sprinklers in one- and two-family dwellings in Massachusetts. Home fire sprinkler installation is an effective injury prevention strategy when a fire occurs in a one- or two-family home, but it is unclear whether the benefits are justified given the costs. In this analysis, we incorporate new empirical evidence regarding the benefits of home fire sprinklers, updated cost and insurance discount data, and updated monetization of the mortality and morbidity benefits associated with reduced fire risk in Massachusetts. We conducted a benefit-cost analysis using present value net benefits methodology. We administered a survey to determine

current home fire sprinkler installation costs and obtained updated insurance discounts associated with the presence of home fire sprinklers. Health benefits were estimated from recent models characterizing associations between sprinkler presence and both deaths and injuries, applying value of statistical life and value of statistical injury for multiple fire-related morbidity outcomes. A sensitivity analysis was performed to determine the implications of input parameter uncertainty, and a breakeven analysis was conducted to assess at which installation cost home fire sprinklers are cost-justified. Fire sprinklers in one- and two-family dwellings in Massachusetts have an average net present value of -$7,000 (95% certainty interval: -$14,000, $1,600). Breakeven analysis indicated a ≥ 50% probability of a positive net present value when overall initial installation costs are between $4,500 and $7,000, depending upon the applicable discount rate. The benefits of fire sprinkler installations in newly-constructed one- and two-family dwellings in Massachusetts do not likely exceed the costs of installation at the present time.

Research Paper 3. Home fire sprinklers in new one- and two-family homes in Massachusetts. The policy discussion about whether the Board of Building Regulations and Standards (BBRS) should require fire sprinklers in newly-built one- and two-family homes in Massachusetts (MA) has been ongoing for over thirty (30) years. Support for these policies center on the potential reductions in civilian and firefighter injuries and deaths, reductions in property damage, and the economic savings associated with the health and property benefits. Opposition to these policies has mainly been based on an argument that the costs of installation and ongoing maintenance outweigh the value of the benefits. This comparison of benefits and costs has been revisited periodically as new evidence has become available. With pending decisions related to modifications of the MA State Building Code, it is timely to consider the current state of evidence regarding benefits and costs of home fire sprinklers. The question regarding the justification for fire sprinklers in newly-built homes is complicated by the fact that there are multiple potential configurations. When included during initial construction of a home, home fire sprinklers can be configured in a variety of ways to accommodate the individual conditions of the project. These decisions will influence cost as well as logistics regarding installation practices. Following analysis of each of the possible interventions, I recommended the following approach for the BBRS to follow regarding home fire sprinklers: 1) the executive and legislative branches of government should work together to develop and implement the suggested incentives to stakeholders to include home fire sprinklers during new construction; 2) the Department of Occupational Licensure should administratively create the abovementioned restricted sprinkler fitter license for licensed plumbers; and 3) the BBRS should include standardized language in the Tenth Edition of the State Building Code to allow municipalities to adopt a local option for the inclusion of home fire sprinklers in newly-built one- and two-family homes.

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Although I was a member of the inaugural class of the Doctor of Public Health program at Tufts University School of Medicine, my path toward completion has taken nearly a decade to completion. This dissertation is a testament to not just countless hours of work by me, but also the support of the members of my Committee in getting me past the finish line. One of my fellow inaugural classmates wrote: “they say it takes a village. I was told by many that the dissertation process can be isolating, but thanks to the following people, it never felt that way” (K. Dong, 2017). I could not have said this any better.

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Abbreviations List

AMA	American Medical Association
BBRS	MA Board of Building Regulations and Standards
BFPR	MA Board of Fire Prevention Regulations
CDC	United States Centers for Disease Control and Prevention
DFS	MA Department of Fire Services
FEMA	United States Federal Emergency Management Agency
FPRF	Fire Protection Research Foundation
IAPMO	International Association of Plumbing and Mechanical Officials
ICC	International Code Council
IRC	International Residential Code
MA	Massachusetts
MFIRS	MA Fire Incident Reporting System
NAHB	National Association of Home Builders
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NIST	United States National Institute of Standards and Technology
NPVB	Net Present Value of Benefits
OMB	United States Office of Management and Budget
USFA	United States Fire Administration
VSL	Value of Statistical Life

Chapter 1: Introduction

1. Statement of the Problem

In Massachusetts, construction means, materials, and methods are regulated by a series of regulations which are based upon international, national, and state-developed standards for their respective disciplines. The international and national standards are developed by highly-standardized consensus-based methods, where only eligible individuals are able to vote on which provisions are included, modified, or deleted. [1-4] Massachusetts' regulatory boards (e.g., the Board of Building Regulations and Standards ("BBRS"), Board of Fire Prevention Regulations ("BFPR"), Board of State Examiners of Plumbers and Gas Fitters ("Plumbing Board"), and Board of Examiners of Sheet Metal Workers ("Sheet Metal Board")) then review these standards and decide which (if any) of the provisions will be adopted / modified / deleted in Massachusetts. [5-8] Members of these boards represent the various stakeholders in their respective disciplines, with all but the BBRS also having a member who represents the general public. [5-8] Although each of these boards must hold public hearings prior to making any changes to their respective regulations, the power to actually adopt the provisions lays solely with a majority vote of these boards, whose decisions are legislative in nature. The Massachusetts Appeals Court determined, in a 1979 case involving the Plumbing Board that: "… the board's action was legislative or political in nature, rather than adjudicatory. There is no requirement that such action be supported by substantial evidence in the record of the proceedings before the board" (p.589). [9] This distinction gives the various boards the authority to determine which provisions enter these regulations, which include life safety regulations, on political grounds instead of scientific evidence.

One recurring example where this problem is apparent is the case of home fire sprinklers in newly-built one- and two-family homes ("home fire sprinklers"). Although these life safety systems have been required in the international standards for over a decade, the BBRS continually removes the provisions from the Massachusetts State Building Code whenever the BBRS is considering a new edition of the Massachusetts State Building Code.

Benefits of the installation of home fire sprinklers have been reported to include: reductions in civilian and fire service deaths and injuries, reductions in magnitude of property damage following a fire event, reductions in water usage and greenhouse gas emissions following fire service operations to extinguish a home structure fire, and reductions in homeowners' insurance premiums. [10-12] Opponents to home fire sprinklers cite high installation costs and uncertainty in effectiveness measures as the reason for lack of support [13]. A number of benefit-cost analyses have been performed, with mixed results, in an attempt to determine whether the value of the benefits is greater than the cost of installation and maintenance. [14-18]

2. Specific Aims

Aim 1: Assessing whether disparities exist in morbidity and mortality resulting from non-institutional residential fires in Massachusetts. We will explore the effectiveness of home fire sprinklers in reducing civilian injuries and deaths in fires occurring in one- and two-family homes in Massachusetts. We will assess whether the observed effectiveness is independent of other risk factors for injuries and deaths in the abovementioned fires using data from the Massachusetts Fire Incident Reporting System ("MFIRS").

Aim 2: To conduct an evidence-based cost-benefit analysis of the impact that mandatory home fire sprinkler installations have on the cost of construction and healthcare-related costs associated with injuries and deaths following home fire events. We will improve estimation of costs attributable to lack of adoption of home fire sprinklers through the calculation of a weighted estimate of the cost(s) of fire-related morbidity and mortality in Massachusetts.

Aim 3: To develop a recommendation to the BBRS relative to the findings in Specific Aim 2 that indicates whether the Board should require home fire sprinklers in the Tenth Edition of the Massachusetts State Building Code. We will present a number of possible action pathways that the BBRS can adopt. We will perform a stakeholder analysis and impact analysis of the action pathways presented to the BBRS.

3. Significance of the Research

The BBRS commissioned two white papers, one in 1995 and one in 2009, both of which noted that the data regarding effectiveness and the benefit-cost were incomplete. [19, 20] The benefit-cost analyses, referenced above, were published concurrently (or shortly after) the release of the latter of these white papers. Since the time of those analyses, multiple parameters have changed, which may have an influence on the net present value benefit.

This dissertation aims to address all of the shortcomings, in the literature, presented by the 1995 and 2009 white papers, while also serving as a benchmark for how the BBRS (and other construction trades-regulating boards) should analyze major policy decisions when being proposed as modifications to their respective boards. This dissertation will improve upon previous assessments for the effectiveness of home fire sprinklers, by assessing multiple risk factors for civilian injuries and deaths, while also addressing the issue of missing data in the national sample of fire-related data, NFIRS. [21]

This dissertation also updates the benefit-cost literature, related to home fire sprinklers, with robust state-specific data. We leverage more recent publications and parameter values, while addressing the uncertainty around these parameters. We incorporate new data regarding the benefits of home fire sprinkler, and gather updated estimates for certain estimates (specifically, insurance discounts and installation costs). This dissertation is also the first time that healthcare-related costs are incorporated into such a benefit-cost analysis with a more granular lens, and the first such time that the benefit-cost analysis includes the environmental benefits associated with home fire sprinklers.

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Chapter 2: Review of the literature

1. Effectiveness of home fire sprinklers

1.1 Fire incident data reporting

The U.S. Fire Administration's ("USFA") National Fire Data Center has been collecting data, at the national level, since the mid-1970s, in a publicly-available database called the National Fire Incident Reporting System ("NFIRS").[1] According to the USFA, approximately 600,000 fire incidents are reported to the database annually, although not all states or fire departments choose to participate.[1] The United States Office of Management and Budget ("OMB") considers NFIRS a voluntary reporting system, not a survey.[2] The overall estimates of the fire problem in the United States come from the National Fire Protection Association's ("NFPA") annual Survey of Fire Departments for U.S. Fire Experience, which is a stratified random sample of fire departments in the United States.[2] The USFA takes the NFPA data to scale the NFIRS data.[2] In its report to OMB, the USFA wrote:

> "One problem with this approach is that the proportions of fires and fire losses differ between the large NFIRS dataset and the NFPA survey sample … Ideally, one would like to have all of the data for the various components come from one consistent data source – the NFIRS. One of the critical pieces of data necessary to do so is missing: the overall population protected by all reporting fire departments …" (p. 11).[2]

Other data issues also exist that influence the potential generalizability, and thus policy recommendations, that can be interpreted using NFIRS data alone.[2] These issues include, but are not limited to: incomplete reporting, reporting bias, and data entry errors. The USFA reports that Massachusetts data quality are consistently high-quality data.[2]

In order to address the abovementioned quality concerns, the Commonwealth of Massachusetts has a law that requires fire departments to report any fire or explosion incident that results in a human injury, death, or property dollar loss to the Department of Fire Services ("DFS").[3] In 2019, 97 percent of MA fire departments either reported fire incident data or certified that no fire incidents occurred within their jurisdictions.[4] These data are reported to the DFS through the Massachusetts Fire Incident Reporting System ("MFIRS"). In order to further incentivize jurisdictions to report their data to MFIRS, the Commonwealth requires participation in order to obtain fire-related funding that is administered by the state.[4]

1.2 Effectiveness estimates in the literature

The annual probability of a fire occurring in a one- or two-family home, in Massachusetts and nationally, has steadily decreased in recent decades.[4-15] Although these fire incidents have become more infrequent, the NFPA reported that rate of civilian injuries was 17% higher in 2020 than in 1980 (31.8 vs. 27.3 civilian injuries per 1,000 reported fires, respectively) and the rate of civilian fatalities in these incidents was 16% higher (8.2 vs. 7.1 civilian deaths per 1,000 reported fires, respectively).[5] The authors hypothesized that "most of the reduction in fire deaths over the past decades has been due to a reduction in fires rather than the prevention of harm after a fire is reported" (p. 1).

Public health advocates have been recommending home fire sprinklers since a 1987 report of the American Medical Association's ("AMA") Council on Scientific Affairs recommended the AMA "encourage legislation that will require smoke detectors and will encourage rapid-response automatic sprinklers in all new residential and commercial buildings" (p. 1620).[16] Researchers at the U.S. National Institute of

Standards and Technology's ("NIST") Applied Economics Office conducted studies on the influence of home fire sprinklers on civilian and fire service injuries and deaths. [17, 18] Seventeen years after Prince George's County, MD enacted home fire sprinkler requirements, a collaboration between the Home Fire Sprinkler Coalition, University of Maryland University College, Prince George's County Fire Department, and Maryland State Fire Marshal's Office found zero civilian fatalities in homes protected with sprinklers versus 101 in homes without sprinklers between 1992-2007.[19] They also found 6 civilian injuries in sprinklered homes versus 328 in homes without sprinklers during the same period.[19]

The authors of the NIST studies found statistically-significant relationships between the presence of home fire sprinklers and reductions in civilian fatalities, but varied results in terms of their effectiveness on civilian injuries. These studies had some notable limitations, including small sample size, and the use of the NFIRS as their primary dataset.[17] The author wrote that a number of observations needed to be dropped from the analysis, due to apparent misreporting of sprinklered dwellings or missing data.[17]

The Prince George's County report was an ecological study and did not assess other risk factors that could have influenced civilian injuries or deaths in the effected homes.[19] These other risk factors included fire alarm presence (referring to smoke detectors) and contents contributing most to fire spread.

Using data from the NFPA's annual Survey of Fire Departments for U.S. Fire Experience, Ahrens (2021) found differences in the rates of both civilian injuries and deaths in homes protected with fire sprinklers versus those without, between 2015-

2019.[20] The author found that the rate of civilian injuries was 28% lower in homes protected with fire sprinklers versus those without (24 vs. 33 civilian injuries, per 1,000 reported home fires, respectively) (p.11).[20] The author also found that the rate of civilian fatalities was 88% lower in homes protected with fire sprinklers versus those without (1.0 vs. 8.1 civilian fatalities, per 1,000 reported home fires, respectively) (p.11).[20]

2. Benefit-cost analysis for home fire sprinklers

The 2014 NIST benefit-cost analysis found that the net present value benefits is primarily affected by five parameters: (1) performance of the sprinklers, in terms of fatalities averted; (2) value of statistical life ("VSL"); (3) time value of money (discount rate); (4) insurance savings; and (5) installation and maintenance costs.[21] Since the publication of the most recent NIST benefit-cost analysis, researchers at FM Global published a white paper regarding the environmental impacts of home fire sprinklers, which have not previously been included in benefit-cost analyses.[22]

2.1 Healthcare-related costs

To-date, all benefit-cost analyses that investigated the impact of home fire sprinklers on injuries and fatalities averted have looked at these metrics in terms of overall numbers and costs.[18, 21, 23, 24] The U.S. Centers for Disease Control and Prevention ("CDC") published an article that characterized the spectrum of non-fatal injuries that were treated in hospital Emergency Departments following residential fires.[25] They found that among all patients, 54.5% (95% CI: 38.3%-70.8%) had a respiratory-related principal diagnosis, compared to 45.5% (95% CI: 29.2%-61.7%) having burn(s) listed as the principal diagnosis.[25]

Lawrence et al (2009) found that the healthcare-related costs varied depending upon the level of care needed (fatality, Emergency Department treat-and-release, treatment at a hospital burn center, treatment at a hospital (not in the burn unit), and treatment at a doctor's office / clinic. [26] Their analysis also was stratified by principal diagnosis (burn only, inhalation only, burn and inhalation, trauma, and other). These data serve as the basis upon which the CDC publishes their cost of injury data in the Web-based Injury Statistics Query and Reporting System ("WISQARS").[27-29] No literature exists that combines the conditional odds of an injury / fatality occurring with the proportional healthcare costs presented in Lawrence et al (2009).

2.2 Insurance discounts

Butry (2014) found that the magnitude of savings associated with reduced homeowner insurance premium is one of the five parameters that most affect the net present value benefit.[21] He found that breakeven between benefits and costs occurred when the insurance discount was 8% at baseline. The Fire Protection Research Foundation ("FPRF") performed a survey of insurance providers to obtain the magnitude of this discount in 2008.[30] In Massachusetts, they found that, of the five (5) insurance companies interviewed (which comprised approx. 41% of total market share at the time), discounts ranged from 5% to 10%, with an average of 7%.[30] Given the risk-based nature of insurance companies (and their associated discounts), one can assume that these numbers are different in 2023; after over decade of reductions in the annual probability of a fire occurring in a one- or two-family home in Massachusetts. In addition, some of the companies that were included in the FPRF report no longer exist or are part of larger companies. As a result, the National Association of Insurance Commissioners reported different companies with different levels of market share for homeowners multiple peril insurance in 2021.[31]

2.3 Environmental impact

Previous benefit-cost analyses have not included the recent research into the environmental impacts of sprinklers. One recent study found that firefighters used 50% less water, and three minutes and seventeen second less time, to extinguish a fire in a standardized home protected with home fire sprinklers versus one without such protection.[22] The authors also found that the presence of sprinklers reduced carbon dioxide emissions by 97.8% in affected fires.[22]

2.4 Installation cost

The FPRF estimates that average cost of home fire sprinklers, to builders, is $1.35 / sprinklered square foot (range: $0.81 - $2.47 / sprinklered square foot) in 2013 US Dollars.[32] In an earlier study, this estimate was $1.61 / sprinklered square foot (range: $0.38 - $3.66 / sprinklered square foot) in 2008 US Dollars.[33] These assessments only reported the builder's self-reported cost of 30 and 51 non-standardized house designs across 10 and 17 communities that have pre-existing home fire sprinkler ordinances in 2008 and 2013, respectively.[32, 33] The wording in these two reports indicate that the researchers incorporated contractor overhead, to the sprinkler contractor, but did not include the final cost that was assessed to the end-user (developer, general contractor, or homeowner). The fact that the selected communities were those that had pre-existing home fire sprinkler ordinances also indicates the presence of established sprinkler installation contractors who may (or may not) specialize in installation of these types of sprinkler system. Due to the lack of such regulation(s) in Massachusetts, the BBRS working groups on home fire sprinklers reported that actual costs are likely higher in Massachusetts.[34, 35]

The NIST benefit-cost analyses based their installation cost estimates on data reported by Brown (2005).[17, 18, 21, 23] Brown (2005) calculated sprinkler installation costs using standardized house plans and asking for costs for multiple types of fire sprinkler systems.[36] To develop this analysis, the author had experts in sprinkler system design and installation provide itemized lists of parts and material, as well as estimated for labor hours for installation of each type of home fire sprinkler system.[36] This methodology is flawed because review of the parts and materials lists (presented on pages 11-28 of Brown (2008)) indicates that many parts are missing and that the quantity of materials is much lower than the installation standard actually requires.[37] These missing items result in cost estimates that are lower than actual installation costs.

3. Incentives to promote home fire sprinkler installation

In 2010, the FPRF published a report on potential incentives that can be offered in order to increase voluntary home fire sprinkler installation, as well as to convince local jurisdictions to adopt home fire sprinkler provisions into their ordinances and / or regulations.[38] This report provided three different levels of incentives that can be offered in exchange for the provision of home fire sprinklers. They included reductions in fire separation distances between adjacent buildings, permission to use different construction types, increasing the number of openings (windows) in sprinkler-protected buildings that are close together, length of cul-de-sacs, and distance between fire hydrants.[38] The membership of the International Code Council ("ICC") has included all of abovementioned suggestions, and more, in each of the editions of the *International*

Residential Code ("IRC") including, and following, the inclusion of the home fire sprinkler provisions in the 2009 IRC.[39, 40]

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Chapter 3: Research Article 1

Association between home fire sprinklers and civilian injuries and deaths in Massachusetts: 2009—2018

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KEYWORDS: Codes & Standards; Buildings; Life Safety; Occupancy; Prevention

ABSTRACT

OBJECTIVES

Rates of injuries and fatalities from structure fires in one- and two-family homes have increased over time; however, few studies have assessed the efficacy of home fire sprinklers in reducing morbidity and mortality. We utilized a comprehensive fire dataset to assess the association between home fire sprinklers and civilian injuries and deaths in single- and two-family home fires over a 10-year period.

METHODS

Structure fire data were extracted from the Massachusetts Fire Incident Reporting System (2009—2018) and were geocoded and connected with parcel attributes and housing and population data from the American Community Survey. Univariable and multivariable logistic regressions were used to determine the association between home fire sprinklers and odds of civilian injuries and deaths, controlling for common risk factors.

RESULTS

A total of 13,867 structure fires were analyzed. In multivariable analysis, presence of home fire sprinklers was associated with a 60% reduction in the odds of civilian injury (OR = 0.40, 95% CI: 0.15—1.12) and 33% reduced odds of civilian death (OR = 0.67, 95% CI: 0.09—5.13) compared to homes without home fire sprinklers.

CONCLUSIONS

Our results suggest that home fire sprinklers may reduce civilian injuries and deaths in single- and two-family homes, compared to similar homes without home fire sprinklers. Despite these reductions being independent of other risk factors evaluated, their magnitudes of reduction are subject to a wide range of uncertainty.

1. INTRODUCTION

A report by the National Fire Protection Association noted that although the absolute number of civilian injuries and deaths occurring in single- and two-family homes had decreased between 1980 and 2020, the rates of civilian injuries and deaths per fire in these homes increased [1]. Nationally, the rate of civilian injuries was 17% higher in 2020 than in 1980 (31.8 vs. 27.3 civilian injuries per 1,000 reported fires, respectively) [1]. The fire fatality rate in these incidents was 16% higher in 2020 than in 1980 (8.2 vs. 7.1 civilian deaths per 1,000 reported fires, respectively). The authors hypothesized that "most of the reduction in fire deaths over the past decades has been due to a reduction in fires rather than the prevention of harm after a fire is reported" (p. 1) [1].

The U.S. Census Bureau estimated slightly more than 1 million one- and two-family homes were built in the United States in 2020 [2]. Within new home construction, one prevention strategy used to reduce injuries and deaths is the inclusion of home fire sprinklers [3, 4]. In 1987, the American Medical Association's (AMA) Council on Scientific Affairs recommended that the AMA "encourage legislation that will require smoke detectors and will encourage rapid-response automatic sprinklers in all new residential and commercial buildings" [5]. Home fire sprinklers were first mandated as part of an overall life safety strategy in the 2009 edition of the *International Residential Code* (IRC), and as an optional strategy since the 2006 edition [6]. The IRC serves as a model code for individual jurisdictions to adopt, at the appropriate level permitted by each jurisdiction's laws (state, county, region, municipality, or district) [7]. Each jurisdiction has the ability to modify the adopted provisions as they feel is best for their constituency. As of July 2019, California and Maryland are the only two states to mandate home fire sprinklers statewide, with two states (Massachusetts and New York) having partial adoption of home fire sprinklers in certain circumstances[8]. In addition, approximately 20 states do not require home fire sprinklers, statewide, but do allow for local jurisdictions to adopt those requirements [8].

Although sprinklers may reduce risks of injury or death associated with fires, opponents of these mandates have argued that the benefits of home fire sprinklers are outweighed by the costs associated with their installation and maintenance, and that other factors (e.g., furniture and synthetic materials brought into the home after occupancy) are more responsible for civilian injuries and deaths [3]. As a result of the uncertainty and associated political disagreements, many states removed provisions for sprinklers [4]. This debate is difficult to resolve because of a dearth of empirical evidence in the literature on the magnitude of the health benefits, if any, of home fire sprinklers.

The U.S. National Institute of Standards and Technology's (NIST) Applied Economics Office conducted studies on the influence of home fire sprinklers on civilian and fire service injuries and deaths [9-12]. The authors of the NIST studies found significant relationships between the provision of home fire sprinklers and a reduction in civilian fatalities, but the findings varied in terms of their effectiveness on civilian injuries. These studies had some important limitations, including a small sample size, potential lack of generalizability [11], and the use of the National Fire Incident Reporting System (NFIRS) as their primary dataset [9-12], which relied on voluntary reporting by fire departments across the nation and suffered from missing and improperly-coded data [13]. Two additional studies focused on the effectiveness of home fire sprinklers in Prince George's County (Maryland) and across California [14, 15]. Although the results of these studies were similar to the NIST studies, causal interpretation was challenging given ecological study designs and lack of evaluation of potential confounders, such as fire alarm presence (referring to single- and multiple-station smoke detectors), presence of human factors contributing to ignition, and contents first ignited.

In the present study, we sought to add to the literature by assessing multiple risk factors for civilian injuries and deaths following uncontained structure fire incidents in single- and two-family dwellings in Massachusetts. Massachusetts was the focus because of the availability of data from the Massachusetts Fire Incident Reporting System (MFIRS), which is a state-specific subset of the NFIRS. Fire departments across Massachusetts are required by law to report all of their official activities to MFIRS, resulting in higher accuracy of data compared to the voluntary reporting to NFIRS [13, 16, 17]. In addition, Massachusetts has adopted, and heavily amended, the IRC since its seventh edition [18]. Among these amendments was removal of the home fire sprinkler provisions. It is therefore timely to consider the association between home fire sprinklers and civilian injuries or deaths, controlling for other important factors and predictors of fire-related health risks.

2. METHODS

The MFIRS dataset is a census of all activities performed by local fire departments in the Commonwealth of Massachusetts [16]. According to the 2018 MFIRS Annual Report, 97% of Massachusetts fire departments reported data in 2018 [16]. For the present analysis, we analyzed MFIRS data from 10 years (2009—2018) because, prior to 2009: (a) home fire sprinklers were not mandatory in Massachusetts, resulting in very low adoption; (b) uncontained structure fires in single- and two-family homes with sprinklers were rare events; and (c) the incidence of injuries or deaths from these fires was also rare [16]. The MFIRS methodology also significantly changed between 2008 and 2009, with a new version adopted in 2009. Our analysis period ended in 2018 because that was the most recent annual dataset available at the time of our analysis.

Property value data were obtained from the standardized assessors' parcel data on the MassGIS system [19]. These included geocoded latitude and longitude, property value, and year of construction for each affected structure. Data on the number of housing units, by structure type, were obtained from the 5-year American Community Survey (2011—2016) [20].

MFIRS data included all structure fires in one- and two-family dwellings in Massachusetts that were not contained within a vessel (e.g., pot/pan, chimney, furnace) or caused by trash or vegetation. Data associated with fires contained within a vessel, which accounted for about 71% of structure fires in the dataset, were excluded because they accounted for less than 10% of all civilian injuries and no deaths in single-and two-family homes [1]. In addition, the data were limited to occupied buildings. We excluded 696 (4.5%) observations that did not report fire alarm or sprinkler presence. Outcomes (i.e., civilian injuries and civilian deaths) were analyzed as binary variables (0 = none, 1 = one or more).

Age of structure was obtained from the "year built" field of the MassGIS data and coded based upon the building code edition in place at the time of construction. We assessed whether changes between building code editions could influence associated fire risks, in a manner not strictly dependent on home age. The resulting variable was coded as: pre-code (pre-1975); first to third edition (1975—1979); fourth edition (1980—1990);

fifth edition (1991—1996); sixth edition (1997—2008); seventh edition (2009—2010); eighth edition (2011—2017); and ninth edition (2018—present).

Extent of structure damage listed in MFIRS was categorized as: minor, significant, heavy, extreme, or none reported. The item first ignited, also derived from MFIRS, was categorized in accordance with the NFIRS Reference Guide [21]. Assessed property values were categorized in quantiles. Dollar loss was categorized using both quantiles and meaningful cut points beyond the 75th percentile: (a) <$1,000, (b) $1,000—4,999 (25th-50th percentile), (c) $5,000—49,999 (50th percentile – between 75th percentile and mean), (d) $50,000—100,000; and (e) >$100,000. The mean dollar loss ($51,006.20) was higher than the 75th percentile ($45,000). Fire spread was categorized according to the NFIRS Reference Guide [21]. Human factors contributing to ignition (person was asleep, impaired by alcohol or drugs, unattended person in need of assistance, physically or mentally disabled, age as a factor, or multiple persons involved / gang activity) was obtained from MFIRS, and was categorized as present or absent [21].

A review of the literature appears to indicate an inverse relationship between various socioeconomic factors and incidence of fires in residential occupancies, where lower socioeconomic status appears to be associated with increased incidence of fire in residential settings [22, 23]. The Commonwealth of Massachusetts has used multiple socioeconomic covariates to designate census tracts as being of concern from an environmental justice perspective, and we followed the classification system from the Commonwealth of Massachusetts' Executive Office of Energy and Environmental Affairs to construct an interpretable summary variable [24]. This included: (a) median household income being less than 65% of the statewide median income, (b) having 40% or more racial/ethnic minorities, (c) having 25% or more lacking English language proficiency, or (d) a combined variable of having 25% or more racial/ethnic minorities and median income less than 150% of the statewide median income. The number of Environmental Justice categories present in each census tract was obtained from MassGIS. Season was also included in the analysis.

Incidents were geocoded using ArcGIS. Geocoding resulted in a 95% exact parcel match, which was then merged with property value data. These data were merged with the MFIRS and census data based on a unique incident ID. Addresses for those data that did not have an exact geocode match were visually inspected to determine whether these data were clustered in the same communities/region. Since the spatial distribution of these addresses was random, we excluded these 707 incidents from further analysis. Outcome variables were converted from count data to binary data based on whether a civilian injury or death was reported by the fire department associated with the structure fire incident.

Data were analyzed using SAS Version 9.4. Univariable analyses were conducted to assess the association between each predictor variable and each of the outcome variables. Multivariable logistic regression was used to assess the associations while controlling for multiple candidate predictors. Variables in the multivariable model were assessed for multicollinearity using a Variance Inflation Factor greater than five as the threshold for serious multicollinearity. Interactions between the model variables were also assessed. Model fit was assessed using the C-statistic. To enhance interpretability, we developed a parsimonious model by removing individual variables from the final multivariable models and examined whether the removal influenced model fit.

A complete listing of variables included in the analyses is provided in Table 1. This listing also includes the source of the data and a brief description of the variable.

3. RESULTS

The MFIRS dataset included 146,884 residential fires in Massachusetts between 2009 and 2018, of which 14,755 occurred in single- and two-family homes (inclusion criteria are presented in Figure 1). As 888 (6.0%) of incident reports had missing MFIRS data for the variables of interest (property value, year built, and human factors), 13,867 residential fires were included in the present analyses, of which 185 (1.33%) were in homes with home fire sprinklers. No differences among the other variables were observed between the residential fires that were excluded and those included in the analyses. As no significant differences in the number of incidents, per 10,000 single- and two-family homes in the affected census tracts, were observed from 2009—2018 (F=0.90, df = 9, p=0.52), the yearly data were aggregated. The responding fire departments logged at least one civilian injury in 734 (5.3%) structure fire incidents and at least one civilian death in 154 (1.11%) structure fire incidents over the 10-year period. Of those incidents in homes protected with sprinklers, the responding fire department reported that 4 (2.2%) and 1 (0.5%) had civilian injuries and deaths, respectively, versus 730 (5.3%) and 153 (1.1%) in those without sprinkler protection.

In the univariable analysis (Table 2), the presence of sprinklers in the home was associated with a 61% reduction in the odds of a civilian being injured (OR = 0.39, 95% CI: 0.15-1.06, p = 0.06) and a 52% reduction in the odds of a civilian death (OR = 0.48, 95% CI: 0.07-3.45, p = 0.46). Fire alarm presence was associated with a 49% reduction in odds of a civilian death (OR = 0.51, 95% CI: 0.37-0.70, $p < 0.001$) and a 7% increase in the odds of civilian injury (OR = 1.07, 95% CI: 0.90-1.26, $p = 0.45$).

The odds of civilian injury or death was associated with the edition of the Massachusetts State Building Code that was in effect when the structure was constructed in both the univariable and multivariable models (Tables 2 and 3). Newer editions of the building code were associated with increased odds of death and injuries compared to earlier editions or homes built prior to the existence of a statewide building code. Although the odds ratios were reduced in the multivariable model relative to the univariate model, odds of civilian death remained higher for houses constructed under the eighth or ninth editions of the Building Code, compared to houses built before the adoption of a statewide building code.

Human factors contributing to ignition were significantly associated with both civilian injury and death in both univariable and multivariable models (Tables 2 and 3). From the multivariable analysis, the odds of a civilian being injured or dying in a fire incident that was ignited due to human factors were 2.25 (95% CI: 1.86-2.73) and 4.56 (95% CI: 3.17-6.56) higher, respectively.

The number of environmental justice categories represented in the affected census tract was not associated with civilian injuries but was associated with civilian deaths, with lower risk seen with a greater number of environmental justice categories. There was lower risk of both civilian injuries and deaths in the summer relative to other seasons. Neither of these variables were included in the parsimonious multivariable model because their inclusion did not affect model fit.

In the parsimonious multivariable model (Table 3) sprinkler presence was associated with a 60% reduction in the odds of a civilian injury (OR = 0.40, 95% CI: 0.15-1.12, p = 0.08) and a 33% reduction in odds of civilian death (OR = 0.67, 95% CI: 0.09-5.13, p = 0.70). Fire alarm presence was associated with a 12% increase in the odds of civilian injury (OR = 1.12, 95% CI: 0.94-1.33, p = 0.33) and a 41% reduction in the odds of a civilian death (OR = 0.59, 95% CI: 0.42-0.83, p = 0.002).

In addition, fire spread, extent of structural damage, and estimated value of property loss were associated with increased odds of civilian injury or death in the univariable analysis (Table 2). The associations with fire spread and value of property loss persisted in the multivariable model (Table 3). Extent of structural damage was not included in the multivariable model. In the multivariable model, certain items contributing to initial ignition of the fire contributed to fire spread and increased odds of civilian injury and death, compared with general materials: (a) liquids, piping, and filters (OR = 5.27 and OR = 3.43); (b) soft goods, wearing apparel (OR = 2.95 and OR = 2.58); (c) organic materials (OR = 3.44 and OR = 0.85); (d) furniture and utensils (OR = 2.08 and OR = 2.29); and (e) storage supplies (OR = 1.93 and OR = 0.67). Structural components / finishes were not associated with greater odds of civilian injury or death than general materials (OR = 0.96 and OR = 0.56, respectively). Property value was inversely associated with odds of both civilian injury and death (Tables 2 and 3).

4. DISCUSSION

The results from our study suggest that home fire sprinklers are associated with reduced odds of civilian injuries in single- and two-family homes in Massachusetts. Interpreting the odds ratio reductions in simpler terms, the presence of home fire sprinklers would have spared 44 civilian injuries (95% CI: 8 to 80) per 1,000 fire incidents) and 4 civilian fatalities per 1,000 fire incidents (95% CI: -15 to 23) in one- and two-family homes in Massachusetts. These associations were independent of the association between civilian injuries or death and fire alarm presence, building contents, age of structure, property value, and fire spread. To our knowledge, our analysis was the first to quantify these associations in a model that included comprehensive fire reporting, ensuring a lack of selection bias. The use of 10 years of data increased our ability to evaluate associations even for relatively infrequent events, although the low number of structures with a fire sprinkler present resulted in wide confidence intervals and magnitudes of reduction subject to wide ranges of uncertainty.

Our findings are relevant to multiple aspects of the policy discussion related to sprinklers. We did confirm that contents in the structure at the time of incident were associated with increased odds of both civilian injury and death. However, these effects were independent of the benefits of home fire sprinklers on reduction in the odds of civilian injuries.

Our analyses also allowed us to evaluate other predictors of civilian injuries and deaths that are important for public policy, with findings that are broadly consistent with the prior literature about risk factors for civilian injuries and deaths in one- and two-family residential dwellings, including associations with the building code edition. We found that the odds of civilian injury and death is increased in homes built under the eighth and ninth editions of the State Building Code. This finding was independent of all other variables included in our analysis. This may be the result of some of the state-specific amendments to the *International Residential Code*, primarily the removal of fire sprinkler requirements while not adjusting other provisions that can be negatively affected by exposure to fire. Examples may include increased use of engineered wood products and changes in the requirements for separation between a garage and the remainder of the dwelling. It is also possible that something changed in more recent home construction that increases the risk associated with home fires. Further analysis is needed to identify specific differences that may explain this finding.

We additionally found that presence of human factors contributing to risk of ignition was not only associated with both civilian injuries and deaths, but was also significantly associated with sprinkler presence. Because a person exhibiting human factors contributing to ignition was 2.7 times more likely to live in a home with fire sprinklers than one without, the presence of these factors confounded the association with civilian deaths (i.e., an OR of 0.48 in the bivariable analysis as opposed to an OR of 0.67 in the multivariable analysis). The confounding effect indicates the importance of considering human factors in future analyses of sprinkler efficacy.

In addition, the finding that fire alarm presence does not result in a significant reduction in odds of civilian injuries is consistent with a recent NIST technical note on human behavior in home fires. Gilbert (2021) found that residents often do not react to fires by evacuating, which has historically been the assumption upon which building code life safety provisions have been created. He presented a new taxonomy that may better explain human behaviors in fires: Investigate, Discuss, Mitigate, Protective Action, and Reentry [25].

Although our findings were robust to inclusion of numerous potential confounders, there are some limitations in interpreting our findings. The Massachusetts

State Building Code does not currently require the installation of home fire sprinklers. This results in their presence in a small number of homes, where they were installed voluntarily or as the result of municipal bylaws. Civilian injuries (734 incidents [5.3% of all incidents]) and deaths (154 incidents [1.1% of all incidents]) were also rare. This limitation was partially addressed by using 10 years of data, the largest timeframe we could assemble, and pooling across years after confirming a lack of variability across years. However, wide confidence intervals remained for most of our estimates, indicating a large degree of uncertainty. It is worth noting that it would be challenging to assemble a sufficiently large dataset to robustly evaluate civilian deaths. Assuming the current prevalence of home fire sprinklers remains constant, a dataset would require approximately 1,152,500 fire incidents (as compared to the 13,867 fire incidents in the current 10-year sample) to have 90 percent power to significantly detect an association of the magnitude we observed for civilian deaths, necessitating a national-scale dataset across many years. Analyses of civilian injuries are more viable, with approximately 74,000 fire incidents needed to be sufficiently powered to detect an association of the magnitude we observed. That said, we subjected our multivariable model to extensive diagnostic testing for multicollinearity and model stability, all of which suggested the model was robust.

Data related to gender and age of injured civilians, other than whether age was a contributing factor to ignition, was not available due to confidentiality restrictions. Future researchers should consider obtaining these data for additional analysis. The extent of injuries and whether an individual was transported to the hospital also could not be assessed. That said, we do not have any reason to anticipate that these covariates would be sufficiently correlated with sprinkler presence to confound associations.

One final possible limitation is that these data represent fire incidents that were reported to fire departments. Greene and Andres (2012) reported differences in reporting of fire incidents that were attended versus unattended in the United States, following a survey by the U.S. Consumer Product Safety Commission [26]. This report suggested that fire incidents are underreported to fire departments. Estimates of underreporting of fire-related injuries and deaths have also been published in the literature [27]. Despite these reports, no data have been presented to indicate differential underrepresentation in homes protected with fire sprinklers versus those that are not.

5. CONCLUSIONS

Our results suggest that home fire sprinklers may reduce the odds of civilian injuries and deaths in single- and two-family homes. Our analyses need to be replicated in other geographic settings with similar high-quality data and larger sample sizes, especially for deaths where associations were highly uncertain. Further, our findings of associations between recent building code editions and increased odds of civilian injuries and deaths from home fires are concerning and also requires further investigation. Further research is required to determine the health benefits of residential sprinkler requirements, which could be used to determine the cost-effectiveness of requiring home fire sprinklers in newly-constructed single- and two-family homes and ultimately to inform building code modifications.

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8. Figures and Tables

Figure 3.1. Flow diagram for incidents included for analysis

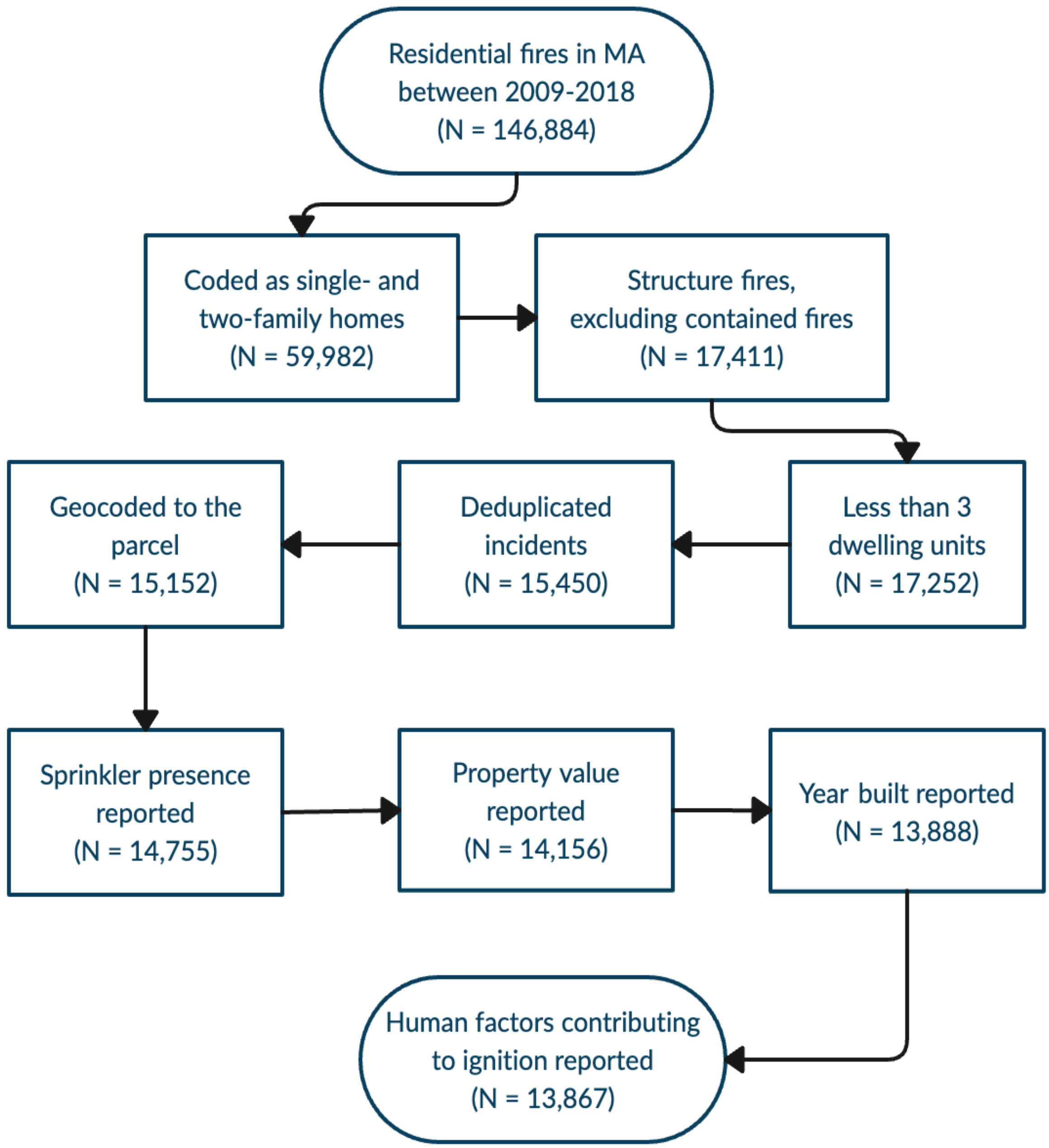

Table 3.1. Listing of variables included for analysis; including source and description.		
VARIABLE TITLE	**SOURCE**	**DESCRIPTION**
Civilian injury	MFIRS	Binary variable identifying whether any civilian injuries occurred as a result of the fire incident.
Civilian death	MFIRS	Binary variable identifying whether any civilian deaths occurred as a result of the fire incident.
Sprinkler presence	MFIRS	Binary variable whether any automatic extinguishing system (sprinklers) was present in the affected house. This does not indicate whether the AES was activated or failed to operate.
Detector presence	MFIRS	Binary variable whether smoke detectors were present in the affected house. This does not indicate whether the detector activated or failed to operate.
Year built	MassGIS Assessors' Database	Year that the original house was constructed, stratified by building code edition in effect at the time of original construction.
Fire spread	MFIRS	Degree to which the fire spread beyond the room of origin (confined to the: room of origin, floor of origin, building of origin, or beyond building of origin)
Item first ignited	MFIRS	"The first item that had sufficient volume or heat intensity to extend to uncontrolled or self-perpetuating fire" (page 4-19) [21]
Extent of structural damage	MFIRS	Degree to which the structure was damage, as reported by the Fire Department.
Value of property loss	MFIRS	Estimated value, in USD, of the dollar loss in terms of property and contents following the fire incident.
Property value	MassGIS Assessors' Database	Property value of the affected structure, including land and structure values.
Number of Environmental Justice categories in census tract	MassGIS Assessors' Database	The number of Environmental Justice categories in the census tract, following geocoding (at the parcel level) of each affected property.
Season	MFIRS	Season during which the fire occurred, based upon date of the incident. Seasons were defined as follows: Winter (January, February, December), Spring (March – May), Summer (June – August), Fall (September – November).

Human Factors Contributing to Ignition	MFIRS	Primary human factor that was determined to contribute to initial ignition (person was asleep, impaired by alcohol or drugs, unattended person in need of assistance, physically or mentally disabled, age as a factor, or multiple persons involved / gang activity).

Table 3.2. Prevalence and odds ratio of any civilian injury and death in single- and two-family homes where a fire occurred in MA between 2009-2018

PARAMETER (n=13,867)	CIVILIAN INJURY N (%)	CIVILIAN INJURY OR (95% CI)	CIVILIAN DEATH N (%)	CIVILIAN DEATH OR (95% CI)
Sprinkler presence[1]				
Yes	4 (2.2)	0.39 (0.15-1.06)	1 (0.5)	0.48 (0.07-3.45)
No	730 (5.3)	--	153 (1.1)	--
Fire alarm presence[2]				
Yes	528 (5.4)	1.07 (0.90-1.26)	85 (0.9)	0.51 (0.37-0.70)
No	206 (5.1)	--	69 (1.7)	--
Building code edition[3]				
Pre-code	501 (5.0)	--	82 (0.8)	--
First through third	16 (3.3)	0.66 (0.40-1.09)	6 (1.3)	1.54 (0.67-3.54)
Fourth	55 (5.1)	1.02 (0.76-1.35)	7 (0.6)	0.79 (0.36-1.71)
Fifth	37 (7.1)	1.45 (1.02-2.05)	6 (1.1)	1.41 (0.61-3.24)
Sixth	27 (3.5)	0.68 (0.46-1.01)	3 (0.4)	0.47 (0.15-1.49)
Seventh	11 (9.7)	2.04 (1.09-3.82)	2 (1.8)	2.17 (0.53-8.94)
Eighth	74 (10.6)	2.26 (1.75-2.92)	37 (5.3)	6.79 (4.57-10.09)
Ninth	13 (11.0)	2.36 (1.32-4.23)	11 (9.3)	12.51 (6.48-24.14)
Fire spread[3]				
Confined to object of origin	44 (2.1)	--	6 (0.3)	--
Confined to room of origin	356 (5.5)	2.67 (1.94-3.66)	25 (0.4)	1.33 (0.54-3.24)
Confined to floor of origin	90 (5.8)	2.84 (1.96-4.09)	25 (1.6)	5.63 (2.31-13.76)
Confined to building of origin	215 (6.3)	3.10 (2.23-4.31)	87 (2.6)	9.02 (3.94-20.67)
Beyond building of origin	29 (8.6)	4.34 (2.67-7.03)	11 (3.3)	11.61 (4.27-31.61)
Item first ignited[3]				
Structural component, finish	108 (2.8)	1.22	16 (0.4)	1.05

		(0.81-1.85)		(0.38-2.86)
Furniture, utensils	78 (6.3)	2.84 (1.84-4.38)	27 (2.2)	5.56 (2.14-14.50)
Soft goods, wearing apparel	102 (8.7)	4.05 (2.66-6.17)	23 (2.0)	5.03 (1.91-13.28)
Adornment, recreational material, signs	8 (3.9)	1.71 (0.77-3.79)	1 (0.5)	1.22 (0.14-10.49)
Storage supplies	21 (5.5)	2.45 (1.38-4.35)	2 (0.5)	1.31 (0.25-6.79)
Liquids, piping, filters	49 (12.7)	6.20 (3.85-9.96)	8 (2.1)	5.33 (1.73-16.39)
Organic materials	114 (8.6)	3.98 (2.63-6.03)	6 (0.5)	1.14 (0.35-3.74)
General materials	29 (2.3)	--	5 (0.4)	--
Other	225 (5.6)	2.51 (1.70-3.72)	66 (1.6)	4.19 (1.68-10.41)
Human factors toward ignition[3]				
Yes	167 (11.1)	2.61 (3.18-3.13)	57 (3.8)	5.00 (3.59-6.97)
No	567 (4.6)	--	97 (0.8)	--
Extent of structural damage[3]				
None observed	158 (3.3)	--	31 (0.7)	--
Minor	298 (4.8)	1.47 (1.21-1.79)	18 (0.3)	0.44 (0.25-0.80)
Significant	106 (8.3)	2.61 (2.02-3.36)	20 (1.6)	2.40 (1.37-4.23)
Heavy	80 (9.7)	3.11 (2.35-4.12)	27 (3.3)	5.12 (3.05-8.65)
Extreme	92 (10.9)	3.56 (2.72-4.66)	58 (6.9)	11.26 (7.23-17.52)
Value of property loss[3]				
<$1,000	112 (2.8)	--	29 (0.7)	--
$1,000 – 4,999	92 (3.8)	1.38 (1.05-1.83)	1 (0.0)	0.06 (0.01-0.42)
$5,000 – 49,999	204 (5.1)	1.89 (1.49-2.39)	14 (0.4)	0.49 (0.26-0.92)
$50,000 – 99,999	100 (8.3)	3.20 (2.42-4.22)	23 (1.9)	2.71 (1.56-4.70)
>$100,000	226 (10.6)	4.20 (3.33-5.30)	87 (4.1)	5.94 (3.89-9.08)

Property value[4]				
$0 – 259,999	206 (6.1)	1.64 (1.31-2.05)	50 (1.5)	1.62 (1.04-2.53)
$251,000 – 366,299	213 (6.1)	1.62 (1.30-2.03)	33 (0.9)	1.02 (0.63-1.66)
$366,300 – 541,199	182 (5.2)	1.37 (1.09-1.72)	39 (1.1)	1.21 (0.75-1.93)
>$541,200	133 (3.8)	--	32 (0.9)	--
No. of Environmental Justice categories in census tract[5]				
0	492 (5.5)	--	100 (1.1)	--
1	132 (4.7)	0.85 (0.70-1.03)	40 (1.4)	1.28 (0.88-1.85)
2	85 (6.0)	1.10 (0.87-1.40)	12 (0.8)	0.76 (0.42-1.39)
3	25 (4.3)	0.78 (0.52-1.17)	2 (0.3)	0.31 (0.08-1.25)
Season[6]				
Winter	223 (5.8)	1.26 (1.02-1.56)	60 (1.6)	2.36 (1.43-3.89)
Spring	199 (5.3)	1.14 (0.92-1.42)	35 (0.9)	1.40 (0.81-2.41)
Summer	147 (4.7)	--	21 (0.7)	--
Fall	165 (5.3)	1.15 (0.91-1.44)	38 (1.2)	1.85 (1.08-3.16)

Notes:

[1] Chi-square p-value for civilian injuries = 0.056; p-value for civilian deaths = 0.456

[2] Chi-square p-value for civilian injuries = 0.445; p-value for civilian deaths <0.001

[3] Chi-square p-value for civilian injuries and civilian death <0.001

[4] Chi-square p-value for civilian injuries <0.001; p-value for civilian deaths = 0.096

[5] Chi-square p-value for civilian injuries = 0.157; p-value for civilian deaths = 0.093

[6] Chi-square p-value for civilian injuries = 0.221; p-value for civilian deaths =0.003

Table 3.3. Multivariable logistic regression of any civilian injury and civilian death among single- and two-family homes where a structure fire occurred in MA between 2009-2018 (n = 13,867 incidents)

PARAMETER	CIVILIAN INJURY OR (95% CI)	CIVILIAN DEATH OR (95% CI)
Sprinkler presence[1]		
Yes	0.40 (0.15-1.12)	0.67 (0.09-5.13)
No	--	--
Fire alarm presence[2]		
Yes	1.12 (0.94-1.33)	0.59 (0.42-0.83)
No	--	--
Building code edition[3]		
Pre-code	--	--
First through third	0.65 (0.39-1.08)	1.57 (0.65-3.78)
Fourth	1.10 (0.82-1.47)	0.95 (0.43-2.11)
Fifth	1.52 (1.06-2.18)	1.91 (0.80-4.54)
Sixth	0.77 (0.51-1.15)	0.68 (0.21-2.19)
Seventh	1.62 (0.84-3.14)	1.76 (0.28-5.01)
Eighth	1.64 (1.22-2.20)	2.59 (1.63-4.12)
Ninth	1.51 (0.82-2.78)	4.52 (2.21-9.24)
Fire spread[4]		
Confined to object of origin	--	--
Confined to room of origin	1.92 (1.38-2.66)	1.16 (0.46-2.89)
Confined to floor of origin	1.63 (1.10-2.40)	2.90 (1.17-7.53)
Confined to building of origin	1.47 (1.02-2.13)	3.46 (1.39-8.59)
Beyond building of origin	1.68 (0.99-2.85)	3.15 (1.05-9.46)
Item first ignited[4]		
Structural component, finish	0.96 (0.63-1.46)	0.56 (0.20-1.57)
Furniture, utensils	2.08 (1.34-3.23)	2.92 (1.10-7.82)
Soft goods, wearing apparel	2.95 (1.92-4.54)	2.58 (0.94-7.04)
Adornment, recreational material, signs	1.60 (0.71-3.57)	0.91 (0.10-8.02)
Storage supplies	1.93 (1.08-3.46)	0.67 (0.12-3.55)
Liquids, piping, filters	5.27 (3.25-8.55)	3.43 (1.08-10.93)
Organic materials	3.44 (2.25-5.24)	0.85 (0.25-2.86)
General materials	--	--
Other	1.71 (1.15-2.56)	1.51 (0.60-3.84)
Human factors toward ignition[4]		
Yes	2.25 (1.86-2.73)	4.56 (3.17-6.56)
No	--	--

Value of property loss[4]		
<$1,000	--	--
$1,000 – 4,999	1.25 (0.94-1.66)	0.06 (0.01-0.47)
$5,000 – 49,999	1.70 (1.34-2.17)	0.48 (0.25-0.92)
$50,000 – 99,999	3.24 (2.42-4.36)	1.82 (0.95-3.12)
>$100,000	4.22 (3.20-5.57)	2.48 (1.50-4.11)
Property value[5]		
$0 – 259,999	1.82 (1.44-2.30)	2.29 (1.40-3.74)
$251,000 – 366,299	1.74 (1.38-2.19)	1.20 (0.72-2.00)
$366,300 – 541,199	1.32 (1.05-1.68)	1.13 (0.69-1.84)
>$541,200	--	--

Notes:

[1] Chi-square p-value for civilian injuries = 0.082; p-value for civilian deaths = 0.699

[2] Chi-square p-value for civilian injuries = 0.206; p-value for civilian deaths = 0.002

[3] Chi-square p-value for civilian injuries = 0.002; p-value for civilian deaths = <0.001

[4] Chi-square p-value for civilian injuries and civilian death <0.001

[5] Chi-square p-value for civilian injuries <0.001; p-value for civilian deaths = 0.002

Chapter 4: Research Article 2

Benefit-cost analysis of fire sprinklers in one- and two-family dwellings in Massachusetts

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KEYWORDS: Cost data; Economic analysis; Buildings; Life safety; Fire protection; Prevention

ABSTRACT

OBJECTIVES

Home fire sprinkler installation is an effective injury prevention strategy when a fire occurs in a one- or two-family home, but it is unclear whether the benefits are justified given the costs. In this analysis, we incorporate new empirical evidence regarding the benefits of home fire sprinklers, updated cost and insurance discount data, and updated monetization of the mortality and morbidity benefits associated with reduced fire risk in Massachusetts.

METHODS

We conducted a benefit-cost analysis using present value net benefits methodology. We administered a survey to determine current home fire sprinkler installation costs and obtained updated insurance discounts associated with the presence of home fire sprinklers. Health benefits were estimated from recent models characterizing associations between sprinkler presence and both deaths and injuries, applying value of statistical life and value of statistical injury for multiple fire-related morbidity outcomes. A sensitivity analysis was performed to determine the implications of input parameter uncertainty, and a breakeven analysis was conducted to assess at which installation cost home fire sprinklers are cost-justified.

RESULTS

Fire sprinklers in one- and two-family dwellings in Massachusetts have an average net present value of -$7,000 (95% certainty interval: -$14,000, $1,600). Breakeven analysis indicated a ≥ 50% probability of a positive net present value when overall initial installation costs are between $4,500 and $7,000, depending upon the applicable discount rate.

CONCLUSIONS

The benefits of fire sprinkler installations in newly-constructed one- and two-family dwellings in Massachusetts do not likely exceed the costs of installation at the present time.

1. INTRODUCTION

Home fire sprinkler installation has been shown to be an effective injury prevention strategy when a fire occurs in a one- or two-family home, but it remains unclear whether the benefits are financially justified given the costs of installation [1-5]. Benefit-cost analyses conducted by researchers at the National Institute of Standards and Technology (NIST) and the National Fire Protection Association (NFPA) found that the installation of home fire sprinklers in one- and two-family homes results in a net present value benefit to the homeowner, but multiple areas of uncertainty remain [1-4, 6-8].

Butry (2014) found that the benefit-cost performance of home fire sprinklers is primarily affected by five parameters: (1) performance of the sprinklers, in terms of fatalities averted; (2) value of statistical life (VSL); (3) time value of money (discount rate); (4) insurance savings; and (5) sprinkler installation and maintenance costs [3]. Since the time of these previous analyses, multiple parameters have changed with a potential influence on the net present value benefit. For example, installation costs have increased since Brown (2005) first presented their findings, as well as national estimates presented by NFPA in 2013 [6, 8], noting that the earlier studies were all based upon the same underlying cost data. Also, savings on homeowner's insurance in an earlier study were obtained from personal communications with a private company whose data help state insurance commissioners and private insurance companies set their homeowner's insurance rates, but these values have been updated in more recent publications [3, 4, 9, 10].

In addition, the earlier studies looked at overall civilian injuries and fatalities associated with fires [3, 4]. Although consideration of overall costs are helpful for a benefit-cost analysis, more granular cost estimates for fire-related injuries and deaths are available, which may influence the findings given differential costs associated with outcomes [11].

There are also some categories of benefits not included in previous studies, such as the environmental impacts of sprinklers. A recent study found that firefighters used 50% less water, and three minutes and seventeen seconds less time, to extinguish a fire in a standardized home protected with fire sprinklers versus one without [12]. The authors also found that sprinklers reduced greenhouse gas emissions by 97.8%. In addition, the previous studies were national-scale, and both the costs and benefits vary considerably across states, where policy decisions related to sprinklers are often made [2].

The aim of the present study is therefore to conduct an updated benefit-cost analysis of sprinklers within an individual state with robust input data (Massachusetts), leveraging more recent publications and parameter values, while addressing the uncertainty around these parameters. Specifically, the present study incorporates new empirical evidence regarding the benefits of home fire sprinklers for estimating the savings associated with reductions in morbidity and mortality, updates installation and homeowners' insurance discount data, uses updated cost data associated with the installation of home fire sprinklers in newly-constructed homes, analyzes costs associated with injuries and deaths with a more granular lens, and incorporates the environmental benefits associated with the presence of fire sprinklers in one- and two-family dwellings.

2. METHODS

2.1 Data sources

2.1.1 Fire statistics

Data related to fire incidents were obtained from the 2009 – 2018 Massachusetts Fire Incident Reporting System (MFIRS) dataset, which is a census of all fire department responses in Massachusetts [13]. Data from the MFIRS are analyzed due to the low prevalence of missing data, and the ability to perform a more geographically targeted benefit-cost analysis than previous studies that were based upon a nationwide sample. These data include all civilian injuries and deaths resulting from structure fires in single- and two-family dwellings (Incident Type = 111 and Property Use = 419 and 400) that were not contained in a vessel (e.g., pot/pan, chimney, furnace/boiler). Additional variables used in this analysis were Disposition (whether the victim was transported to the ED), Primary Apparent Symptom (PAS), and Severity of injury.

We reduced the number of categories within the PAS and Severity variables to align with the outcomes reported for cost of injury or death [11]. PAS was recoded as: 1=Respiratory, 2=Burns, 3=Combo Respiratory and Burns, and 4=Other. Severity was recoded as: Minor and Moderate = Treat and Release, Severe and Life-threatening = Inpatient, and Death = Death.

Summary data related to overall fires in one- and two-family homes in Massachusetts between the years 2009-2019 were obtained from the annual reports of the State Fire Marshal's Office [13-23]. These included the estimated number of fires occurring in Massachusetts in the affected year, as well as estimated value of property damage as a result of the fire.

2.1.2 Heath-related data

Data related to the effectiveness of home fire sprinklers related to reductions in injuries and deaths following fires in one- and two-family homes are obtained from

Zemel et al. (2023), using prior publications by the NFPA and NIST for sensitivity analyses [1, 5, 7]. Zemel et al. (2023) estimated a 60% reduction in the odds of civilian injuries (OR = 0.40, 95% confidence interval (CI) 0.15-1.12) and a 33% reduction in the odds of civilian deaths (OR = 0.67, 95% CI 0.09-5.13) [5]. To incorporate the extremely wide CIs without assuming that presence of home fire sprinklers could increase the odds of civilian injuries and deaths following fire events in one- and two-family homes, we truncated these distributions and assumed a lower bound of a 0% decrease in the odds of civilian injuries or deaths in our Monte Carlo analyses.

Savings attributable to reductions in morbidity, as well as the medical cost savings associated with reductions in fatal fires, were derived from Lawrence et al. [11]. Lawrence et al. (2009) categorized outcomes as: fatal, treated at a hospital burn center, treated at hospital (not in the burn unit), treated and released from the emergency department, and treated at a doctor's office / clinic. In addition, each of these treatment dispositions were stratified by primary apparent symptom (all cause, burn, inhalation, burn & inhalation, trauma, and other) (Table 19, p. 30). Using these data in combination with the conditional odds of each combination occurring following a fire event can give a more precise estimate of the cost savings associated with civilian injuries and fatalities averted by the installation of home fire sprinklers. These data were originally reported in 2000 dollars, and we adjusted them to 2022 dollars using an adjustment factor of 1.7 based upon overall inflation [24]. Inpatient costs were assumed to be in-line with the "other hospital" costs in Table 16 of Lawrence et al. (2009), as Massachusetts only has three burn centers (all of which are in Boston) [25].

Value of Statistical Life (VSL) was based upon the Weibull distribution that is recommended by the US Environmental Protection Agency [26]. Previous analyses of home fire sprinklers focused on a central estimate value for VSL, without addressing the underlying uncertainty of the value itself [3, 4].

2.1.2 Cost data

Costs associated with supplying water were obtained from the 2017 Massachusetts Water Rate Survey, which included data from 237 public water suppliers in Massachusetts [27]. Cost of a standard 5/8" water meter and a 3/4" water meter were obtained. We assumed that the rate for the increased meter was not adjusted since the time of the survey. As such, those estimates were adjusted to 2022 dollars using an inflation factor of 1.19 [24].

Additionally, a survey was completed by sprinkler contractors who were identified by the Massachusetts Fire Sprinkler Coalition as routinely installing home fire sprinklers across Massachusetts. The survey instrument can be viewed in Appendix A. The survey design and instrument were reviewed by the Tufts University Social, Behavioral & Educational Research IRB and determined to not be human subjects research. The survey was distributed to the identified installers via email, and requested that installers provide estimated costs for the installation of a code-compliant home fire sprinkler system in three prototypical homes that were first used in the 2005 NIST *Economic Analysis of Residential Fire Sprinkler Systems* in order to standardize the costs [6].

Installers were asked: the type of system they would likely install (standalone, networked / interconnected, or other); whether a backflow preventer would be required;

total cost; phases included (design, permitting, and/or installation); and percent profit / material markup used. As control questions, installers were asked approximately how many new home fire sprinkler system installations they performed in MA between 2021 and 2022, as well as the approximate percentage of the firm's workload that was made up on similar installations between 2021 and 2022. In order to address geographic variability in pricing, the installers were also asked to provide estimated pricing in four different cities across the Commonwealth (Lowell, Boston, Worcester, and Springfield).

In addition to the survey, we calculated the estimated cost for a code-compliant standalone sprinkler system in Boston using the R.S. Means Online project estimating software tool (https://www.rsmeansonline.com/). Although installers were asked if a backflow preventer would be required, the cost of the associated backflow preventer was not included because Massachusetts allows the use of a less-costly double-check valve in those instances where a backflow preventer would otherwise be required [28].

2.1.3 Environmental benefits

Environmental benefits were derived from Wieczorek et al., which estimated the equivalent mass of CO_2 generated in a fire in a house containing sprinklers and one without sprinklers [12]. The estimate of the Presidential Interagency Working Group was used to calculate the social cost of carbon [29]. The value of carbon savings, per house built, was obtained by multiplying the average carbon savings, per fire incident, by the social cost of carbon. The resulting present value of climate savings was included as an incremental societal benefit.

2.1.4 Property-related statistics

The total number of one- and two-family houses was obtained from the American Community Survey for the years 2009 through 2019 [30]. The annual probability of a fire in a one- or two-family dwelling was obtained by dividing the total number of fires occurring in one- and two-family homes (reported in the Annual Report of the State Fire Marshal's Office) by the total number of one- and two-family homes [13-23, 30].

Updates to estimated savings on homeowner's insurance premiums were obtained using similar methods to those applied elsewhere [10]. A listing of the top ten property and casualty insurance providers, for homeowners multiple peril policies, was obtained from the National Association of Insurance Commissioners 2021 Market Share Report [31]. Each individual company was called and asked the discount on the total policy for homeowners' insurance in MA for the installation of home fire sprinklers in a one- or two-family homes. For those companies that required working with an independent insurance agent, one was contacted and asked for the same data.

Average annual homeowners insurance premiums for Massachusetts were obtained for the years 2008-2019 from the Insurance Information Institute [32]. These annual premiums were then adjusted to 2022 dollars using the appropriate adjustment factors based upon total inflation [24].

2.2 Analysis

2.2.1 Primary analysis

Data analysis was performed in a manner consistent with ASTM E 1074-15 (Reapproved 2020): *Standard Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems* [33]. Benefits and costs were discounted to present values to account for the fact that costs and benefits occur at different times.

The Uniform Present Value method of discounting was used in order to determine the present value of any benefits, as well as recurring costs, over a period of 30 years, using the method described in Table 1 of ASTM E 917-17: *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems* [34]. A diagram showing all of the inputs is presented in Figure 4.1.

The present value of benefits was calculated using the following formula:

$$PVB = PVDI + PVCS + PVPL + PVI \quad (1)$$

where:

- PVB is the present value of benefits, for a given fire (F), in a given home,
- $PVDI$ is the present value of savings from death or injury averted, in 2022 dollars,
- $PVCS$ is the present value of climate savings,
- $PVPL$ is the present value of property loss, and
- PVI is the present value of insurance savings.

Present value of death or injury averted was calculated using the following formula:

$$PVDI = P(F) * (V_{inj} + V_{mc\_d} + V_{death}) * U \quad (2)$$

where:

- $PVDI$ is the present value of savings from death or injury averted, in 2022 dollars,
- $P(F)$ is annual probability of a fire occurring in a one- or two-family home in Massachusetts [13-23],
- V_{inj} is the value of injuries averted,
- V_{mc_d} is the value of medical costs associated with deaths averted,

- V_{death} is the value of deaths averted,
- U is the uniform present value factor, as described in ASTM E 917-17 [34], using a 5 percent discount rate over a discounting period of 30 years,

The three components of PVDI, V_{inj}, V_{mc_d}, and V_{death}, are comprised of the conditional probability of a particular scenario multiplied by the reduction in annual odds and the monetary value of that reduction. These are calculated using the following three formulas:

$$V_{inj} = P(PAS \mid DISP \mid OUTCOME \mid INJ) * \Delta_{inj} * VSI(PAS \mid DISP \mid OUTCOME) \quad (3)$$

$$V_{mc\_d} = P(PAS \mid DISP \mid OUTCOME \mid DEATH) * \Delta_{death} * VMC(PAS \mid DISP) \quad (4)$$

$$V_{death} = P(PAS \mid DISP \mid OUTCOME \mid DEATH) * \Delta_{death} * VSL \quad (5)$$

where:

- V_{inj} is the value of injuries averted,
- V_{mc_d} is the value of medical costs associated with deaths averted,
- V_{death} is the value of deaths averted,
- $P(*)$ is the probability,
- $P(k \mid i \mid \ldots z)$ is the conditional probability of outcome k, conditioned upon i, which is conditioned upon each following parameter through z,
- Δ_{inj} is the reduction in the annual odds of an injury, following fire (F), in a house protected with only smoke alarms versus one that is protected with both smoke alarms and home fire sprinklers [5],

- Δ_{death} is the reduction in the annual odds of a death, following fire (*F*), in a house protected with only smoke alarms versus one that is protected with both smoke alarms and home fire sprinklers [5],
- *VSI(k | i | … z)* is the Value of Statistical Injury of outcome *k*, conditioned upon *i*, which is conditioned upon each following parameter through *z*,
- *VMC(k | i)* is the Value of the Medical Cost of outcome *k*, conditioned upon *i*, presented in Lawrence et al (2009), which is adjusted to 2022 dollars [11],
- *VSL* is the Value of Statistical Life, measured in 2022 dollars [26],
- *PAS* is the primary apparent symptom, as recorded at the time of fire incident (burn, respiratory, combination of burn & respiratory, or other),
- *DISP* is whether that civilian was transported to the emergency department (ED) following the fire incident, and
- *OUTCOME* is whether the patient was: treated and released, admitted to a hospital, or died.

Data analysis to determine the conditional probabilities necessary to calculate the *PVDI* was performed using SAS Software, version 9.4 [35]. Missing data were imputed by multiple imputation using fully conditional specification. Logistic regression using a generalized logit model was used to calculate predicted probabilities. This analysis increased the precision of the estimates presented in Butry (2009) by specifying the variables according to whether the affected party was transported to the hospital, what their primary apparent symptom was, and whether they were treated and released, admitted to the hospital, or died. All other data analysis was performed using Microsoft Excel, version 16.70 [36].

Present value of climate savings was calculated using the following formula:

$$PVCS = P(F) * CS * SVC * U \quad (6)$$

where:

- *PVCS* is the present value of carbon savings, in 2022 dollars,
- *P(F)* is the annual probability of a fire occurring in a one- or two-family home in Massachusetts [13-23],
- *CS* is the estimated reduction in carbon dioxide emissions, per structure fire in a one- or two-family home, associated with the presence of home fire sprinklers versus in a similar home without home fire sprinklers [12],
- *SVC* is the social value of carbon, using a 3 percent stochastic discount rate, adjusted to 2022 dollars ($68.48) [29], and
- *U* is the uniform present value factor, as described in ASTM E 917-17 [34], using a 5 percent discount rate over a discounting period of 30 years,

Present value of property loss was calculated using the following formula:

$$PVPL = P(F) * ERPL * U \quad (7)$$

where:

- *PVPL* is the present value of property loss,
- *P(F)* is the annual probability of a fire occurring in a one- or two-family home in Massachusetts [13-23],
- *ERPL* is the estimated reduction in property loss, in a given fire, associated with the presence of home fire sprinklers versus in a similar home without home fire sprinklers, estimated to be 62 percent [1], and
- *U* is the uniform present value factor, as described in ASTM E 917-17 [34], using a 5 percent discount rate over a discounting period of 30 years,

Present value of insurance savings was calculated using the following formula:

$$PVI = Ins\_Prem * Ins\_Disc * U \quad (8)$$

where:

- *PVI* is the present value of insurance savings,
- *Ins_Prem* is the average annual insurance premium for multiple peril homeowners insurance in Massachusetts from 2009 to 2019,
- *Ins_Disc* is the percent discount off of the total insurance premium as a result of the presence of home fire sprinklers, and
- *U* is the uniform present value factor, as described in ASTM E 917-17 [34], using a 5 percent discount rate over a discounting period of 30 years,

Present value of the cost was calculated by adding the cost for construction of the system and the annual cost of operation and maintenance of the home fire sprinkler system. Mathematically, this is shown as:

$$PVC = C_{install} + (C_{OPM} * U) \tag{9}$$

where:

- *PVC* is the present value of the cost of a home fire sprinkler,
- $C_{install}$ is the total cost to install and commission a home fire sprinkler system, and
- C_{OPM} is the annual cost for operation and maintenance of a home fire sprinkler system. This is primarily comprised of the annual cost of an increased water meter diameter feeding the house.
- *U* is the uniform present value factor, as described in ASTM E 917-17 [34], using a 5 percent discount rate over a discounting period of 30 years,

The net present benefit of the home fire sprinkler is defined as *PVB – PVC*. If the difference is positive, then the addition of home fire sprinklers is a net benefit. If the difference is negative, then the addition of home fire sprinklers to one- and two- family homes is a net cost.

2.2.2 Uncertainty and sensitivity analysis

Many of the parameters included in the primary analysis are uncertain, and the influence of that uncertainty was not fully addressed in previous analyses. In order to assess the impact of the uncertainty on the value of net present benefit, a sensitivity analysis was performed by calculating the net present benefit following 10,000 draws, with every draw varying each of the assumptions randomly using a Monte Carlo distribution with a fixed seed in order to achieve reproducible results [36]. A 95% certainty interval was obtained from the resultant distribution. In addition to performing an uncertainty analysis, a sensitivity analysis was performed by varying the discount rate, using discount rates of 3%, 5%, and 7% to be in-line with the OMB recommendation for regulatory analysis [37]. Crystal Ball Software, Version 11.1.3, was used to perform the uncertainty and sensitivity analyses [36].

2.2.3 Breakeven analysis

A breakeven analysis was performed to determine the estimated installation cost that will more likely-than-not (i.e., probability greater than 50%) result in a positive net benefit (i.e., a value greater than $0.00) associated with the installation of home fire sprinklers, looking across alternative discount rates, while performing the uncertainty and sensitivity analyses described above. Installation costs where the probability of a positive net benefit greater than 75% and 95% were also simulated. These breakeven analyses were performed using the Decision Optimizer feature of the Crystal Ball software [36].

3. RESULTS

3.1 Primary analysis

3.1.1 Fires occurring in one- and two-family homes in Massachusetts between 2009 and 2019

Summary statistics for data obtained from MFIRS and the Annual Reports of the MA State Fire Marshal's Office are presented in Table 4.1. Between the years 2009 and 2019, the annual probability of a fire occurring in a one- or two-family dwelling ranged from 2.37 to 3.20 fires per year for every 1,000 one- or two-family dwellings in Massachusetts, with a mean of 2.74. This number has been trending downward across the eleven years reported, with 2.48 fires for every 1,000 one- or two-family dwellings in Massachusetts reported in 2019.

Although some variability was observed between years, the probability of total number of civilian injuries and deaths associated with an uncontained structure fire in a one- or two-family dwelling in Massachusetts was observed to be lower in homes protected with fire sprinklers and smoke alarms than in those protected with smoke alarms alone (Table 4.1).

3.1.2 Value of property loss due to fire event

Estimated property loss, per fire, ranged from $17,000 to $27,000 in 2022 US dollars, with a mean and median of $22,000. Previous studies reported that the presence of sprinklers in one- and two-family dwellings is associated with a 62 percent reduction in property loss [1]. The resulting range of savings, per fire, is between $11,000 and $17,000, with a central estimate of $15,000, resulting in a present value of savings from property loss reduction of $600 [1].

3.1.3 Installation costs

Of the seven fire sprinkler contractor firms surveyed, three reported that they have not installed any home fire sprinkler systems in one- or two-family homes in the past two years. Responses to the survey were obtained from the remaining four contractors (Table 4.2). Reported installation costs ranged from $5.12 to $13.24 per sprinklered square foot for a 1,171 square foot ranch; $2.40 to $8.24 per sprinklered square foot for a 3,338 square foot colonial; and $4.65 to $8.86 per sprinklered square foot for a 2,257 square foot townhouse. Contractor profits were reported from three of the four contractors and ranged from 12 to 20 percent. Total installation costs ranged from $6,000 to $27,500 across the contractors, system types, and housing configurations. The median installation cost of $13,500 was used for this analysis.

3.1.4 Insurance discount

Insurance discounts in 2021 for the ten largest multiple peril homeowners' insurance carriers in Massachusetts are reported in Table 4.3. Insurance discounts ranged from zero to eight percent, with three insurance carriers giving up to ten percent for houses equipped with a full NFPA 13 system (versus the NFPA 13D or 13R systems that are the subject of this analysis), with the median and mode both being a two percent discount. The present value of insurance savings was $500.

3.1.5 Estimated savings from reduction in injuries and deaths

The estimates for value of statistical injury and the medical costs for those victims who ultimately died are reported in Table 4.4. The central estimate of $10,700,000 was used for the value of statistical life [26]. Combining these estimates with the values from Zemel et al. (2023), the present value of the reduction in death and injury associated with the presence of home fire sprinklers was $1,900. This was based upon a 5% discount rate and an annual probability of fire being 2.7 fires per 1,000 one- and two-family dwellings in Massachusetts.

3.1.6 Estimated climate savings

Using the social cost of carbon, presented in Rennert et al (2021), combined with the reduction in CO_2 emissions following a fire event presented by Wieczorek et al (2010), the estimated climate savings is $30, with a present value of carbon savings of $1.24 [12, 29].

3.1.7 Net present value

Central estimates for the parameters used to calculate the net present value are presented in Table 4.5. Applying a 5 percent discount rate, the present value of the benefits was $3,000, while the present value of costs (initial installation cost and operation and maintenance cost) was $14,000. The resulting net present value was -$11,000.

3.2 Uncertainty and sensitivity analyses

3.2.1 Full model

Given parametric uncertainty (Table 4.6), our Monte Carlo analysis indicated a mean net present value estimate of -$7,000, a median net present value estimate of -$7,300, and a 95% certainty interval of -$14,000 to $1,600 (Table 4.7). Initial installation cost accounted for 56 percent of the uncertainty in the net present value estimate. Holding initial installation cost fixed, the uncertainty surrounding the percent reduction in the probability of death associated with the presence of home fire sprinklers accounted for 63 percent of the remaining uncertainty. Further, the value of statistical life, discount rate, insurance discount percentage, and annual probability of a fire accounted for 26, 5, 4, and 1 percent, respectively. The remaining parameters, including annual insurance premium, value of property loss, and reduction in probability of injury associated with the presence of home fire sprinklers, each accounted for less than one percent of the uncertainty in the net present value estimate.

3.2.2 Breakeven analyses

With a 5% discount rate, a positive net present value had a greater than 50% probability of occurring with an initial installation cost of $5,500 ($2.44/sf) (Table 4.8). These values increased to $7,000 ($3.10/sf) using a 3% discount rate and were reduced to $4,500 ($2.00/sf) using a 7% discount rate. The simulation indicated greater than a 95% probability of a positive net present value when installation costs were less than, or equal to, $3,000 ($1.33/sf), $2,500 ($1.11/sf), or $2,000 ($0.89/sf) for discount rates of 3%, 5%, and 7%, respectively. The relative contributions of parametric uncertainty to overall uncertainty were similar for the breakeven analysis as for the net present value analysis (Table 4.9).

4. DISCUSSION

Our benefit-cost analysis indicated that current conditions in Massachusetts most likely result in a negative net present value of benefits for the installation of sprinklers in newly-constructed one- and two-family dwellings, albeit with appreciable uncertainty. In contrast to previous studies which reported positive net present value of benefits, the present study used parameters that differed in terms of annual probability of fire, calculation of present value of deaths and injuries averted, estimates for insurance discounts, initial cost for installation of sprinklers, and value of statistical life, while also accounting for uncertainty across the analysis. The two differences with the greatest impact were the initial installation cost for home fire sprinklers and the insurance discount associated with the presence of fire sprinklers in one- and two-family dwellings.

Initial cost for installation was obtained through the completion of a survey using the same prototypical house layouts originally used by Brown (2005). A comparison between our cost estimates and those reported by the NFPA and Newport Partners in 2008 and 2013 are presented in Table 4.10. Installation costs for fire sprinklers in one- and two-family homes have increased for both the unit cost (dollars per sprinklered square foot) and total cost from the estimates previously published [3, 4, 6, 8]. This may be a true increase, but it may also be the result of local market forces in Massachusetts, whereas the previous studies used national estimates for the initial installation cost. In addition, our insurance discount rate values differed from those reported by Fire Protection Research Foundation in 2008, which reported insurance discounts ranging from five to ten percent, with a median value of seven percent [10]. Both of these differences point to the need for routine updating of values as well as the use of state-level data where available for decision-making within states.

Another difference that impacted our model findings was the annual probability of a fire occurring in a one- or two-family house in Massachusetts. The annual probability of a fire has trended downward over the last ten years (see Table 4.1), which results in lower present value estimates for parameters such as *PVDI*, *PVPL*, and *PVC*. The current parameter estimate of 2.7 fires per 1,000 one- or two-family homes in Massachusetts is lower than the 3.6 fires per 1,000 one- and two-family homes presented in Butry (2009) [4].

An additional uncertainty relates to the efficacy of sprinklers themselves. This parameter accounted for 66% of the model uncertainty in both the uncertainty and breakeven analyses, when holding initial installation cost and discount rate constant. The estimates from Zemel et al. (2023) were derived from multivariable analyses that included other risk factors for civilian injuries and deaths following a fire event (presence of smoke detectors, extent of fire spread, extent of property damage, amount of property loss, value of the property, presence of human factors, age of structure, and item first ignited) but had wide confidence intervals given the limited presence of home fire sprinklers coupled with the rarity of the outcome (injury or death) [5]. To give a sense of the sensitivity of our conclusions to the estimates selected, Ahrens (2021) reported that civilian injuries were 28 percent lower and civilian deaths were 88 percent lower in homes protected with sprinklers versus those with fire alarms only [1]. For illustrative purposes, if we assume an 88 percent reduction in the probability of death following a fire while holding all other parameter values as in our primary analysis, the average net present value is increased from -$7,000 to -$5,000, with a 95% certainty interval of -$13,000 to $5,000. With this parameter change, the net present value had a greater than 50% probability of being positive when the initial installation cost was $9,750 ($4.32/sf), $7,500 ($3.33/sf), and $6,000 ($2.66/sf) with discount rates of 3%, 5%, and 7%, respectively. Thus, while the central estimate remains negative, a much greater efficacy of home fire sprinklers in reducing civilian deaths would increase the likelihood of positive net benefits (given cost estimates ranging from $6,000 ($2.66/sf) to $27,500 ($12.19/sf)). In contrast, removing the human factors variable from the multivariable model in Zemel et al. (2023) would reduce the estimate for civilian deaths from a 33% reduction to a 15% reduction, decreasing the average net present value to -$7,500 and reducing the likelihood of positive net benefits. More research is necessary to reduce the magnitude of uncertainty around this estimate in order to better inform future policy discussions.

The effects of discount rate on benefit-cost analyses are well-documented in the literature [29, 38-41]. Due to these differences, the United States Office of Management and Budget requires that all regulatory analysis studies be conducted using both a 3 percent and 7 percent discount rate. Previous studies used a constant discount rate and did not control for these effects in their sensitivity analyses. Our uncertainty analyses reinforced the importance of considering the range of discount rates, as the discount rate accounted for 5 percent of the uncertainty in the overall model, when controlling for cost.

We also incorporated environmental benefits using the social cost of carbon, which has been commonly used to estimate the impact of interventions that result in CO_2 reduction [29]. There is appreciable uncertainty in this value; the initial Obama-era estimate was $51 per ton of CO_2 reduced, using a 3 percent constant discount rate [29]. Recent research has centered on the importance of discount rate for the social cost of carbon [29, 38-40] and willingness to pay studies that may require adjustment to economic factors [29, 34]. While this was a modest contributor to benefits, our analysis reinforced the value of a more holistic benefit-cost framework.

Our analysis offers some important insights regarding both the analytical approaches that should be applied in future analyses of home sprinklers and the areas in which more research is required. On the former, propagation of parametric uncertainty is important for a meaningful characterization of findings, as well as to identify areas of substantial uncertainty that could be addressed with additional research. Our findings also reinforced the importance of utilizing state-level data for state-level decision-making when such data are available. On the latter, uncertainty surrounding installation cost was the leading contributor to model uncertainty, and this can be readily addressed with extensive local data collection. We were able to develop a reasonable range of values through a survey instrument sent to multiple local companies, but such data could be collected for a range of individual properties of varying types to provide a more precise estimate for a given state. In addition, the efficacy of home fire sprinklers in reducing mortality and morbidity is clearly an area with appreciable uncertainty that could be reduced with additional study.

5. CONCLUSIONS

The costs of fire sprinkler installation in newly constructed one- and two-family dwellings in Massachusetts likely exceed the benefits given the current initial installation costs and other factors, such as the current magnitude of the homeowners' insurance discount and the declining annual probability of fire. Better understanding is needed regarding the effectiveness of home fire sprinklers at reducing civilian fatalities. Future research should also investigate the effects of various strategies that reduce the initial installation cost or the development of incentives that may offset the negative net present values presented in this paper.

6. ACKNOWLEDGEMENTS

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8. TABLES AND FIGURES

Table 4.1. Selected statistics for one- and two-family dwellings from 2009-2019

Parameter		Year											Mean
		2009 (N=1491)	2010 (N=1523)	2011 (N=1461)	2012 (N=1574)	2013 (N=1535)	2014 (N=1402)	2015 (N=1445)	2016 (N=1479)	2017 (N=1445)	2018 (N=1400)	2019	
Annual probability of fire, per 1,000 dwellings[1]		3.09	3.18	3.20	2.83	2.80	2.65	2.58	2.49	2.43	2.37	2.48	2.74
Civilian injuries, N (N per 100 fires)[2,3]													
	Sprinklered	1 (0.1)	2 (0.1)[4]	0 (0.0)	3 (0.2)[5]	3 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.1)	--[6]	11 (0.1)
	Smoke alarm	126 (8.5)	100 (6.6)	90 (6.2)	96 (6.1)	122 (8.0)	108 (7.7)	99 (6.9)	115 (7.8)	85 (5.9)	91 (6.6)	--[6]	1032 (7.0)
	Total	127 (8.5)	102 (6.7)	90 (6.2)	99 (6.3)	125 (8.1)	108 (7.7)	99 (6.9)	115 (7.8)	85 (5.9)	93 (6.6)	--[6]	1043 (7.1)
Civilian deaths, N (N per 100 fires)[2,3]													
	Sprinklered	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	2 (0.1)[4]	0 (0.0)	0 (0.0)	0 (0.0)	--[6]	3 (0.0)
	Smoke Alarm	17 (1.1)	12 (0.8)	25 (1.7)	14 (0.9)	15 (1.0)	21 (1.5)	30 (2.1)	30 (2.1)	27 (1.9)	22 (1.6)	--[6]	213 (1.4)
	Total	17 (1.1)	12 (0.8)	25 (1.7)	15 (1.0)	15 (1.0)	21 (1.5)	32(2.2)	30 (2.0)	27 (1.9)	22 (1.6)	--[6]	216 (1.5)
Property damage (2022 dollars)[1]		$19,000	$18,000	$17,000	$23,000	$22,000	$19000	$22,000	$27,000	$24,000	$24,000	$24,000	$22,000
Avg. insurance premium (2022 dollars)[7]		$1,400	$1,400	$1,400	$1,500	$1,600	$1,600	$1,700	$1,800	$1,800	$1,800	$1,800	$1,600

Footnotes

1. Source: Annual reports of the Massachusetts State Fire Marshal's Office for the years 2009-2019 [13-23].
2. Data reported for uncontained structure fires only.
3. The term "civilian" refers to anybody who is not affiliated with the fire service (public, residents, police, EMS, etc).
4. Both injuries occurred during the same event.
5. All incidents occurred between two events.
6. MFIRS data, for analysis, was not available for calendar year 2019.
7. Source: Insurance Information Institute (2022) [32].

Table 4.2. Installation costs for home fire [1]

Installer #	System type	House type (cost per sprinklered square foot, 2022 dollars) Ranch (1,171 SF)	Colonial (3,338 SF)	Townhouse (2,257 SF)	Percent profit
1	Standalone	$6,000 ($5.12)	$8,000 ($2.40)	$10,500 ($4.65)	15%
2	Standalone	$10,000 ($8.54)	$20,000 ($5.99)	$17,000 ($7.53)	12%
3	Standalone	$15,500 ($13.24)	$27,500 ($8.24)	$20,000 ($8.86)	20%
4	Interconnected	$6,000 ($5.12)	$17,000 ($5.09)	$11,500 ($5.09)	--[2]

Footnotes
1. Source: Survey in Appendix A.
2. Installer number 4 was not willing to share their percent profit.

Table 4.3. Insurance discounts for home fire sprinklers

Insurance company	Discount amount (%)	Source	Note
1	2.00%	Company phone center	
2	2.00%	Company phone center	An affiliate company offers 7% (Source: Independent agent)
3	8.00%	Independent insurance agent	10% offered if full NFPA 13 system
4	8.00%	Independent insurance agent	10% offered if full NFPA 13 system
5	2.00%	Independent insurance agent	
6	0.80%	Independent insurance agent	
7	7.00%	Independent insurance agent	10% offered if full NFPA 13 system
8	--	Unable to reach company representative	Unable to reach company
9	2.00%	Company phone center	
10	0.00%	Company phone center	

Table 4.4. Unit cost estimates for home fire injuries (2022 dollars) [1]

Primary apparent symptom	Medical Cost of Death	Outcome Inpatient	Emergency Department	Outpatient clinic / doctor's office
All cases	$28,133	$283,824	$38,876	$21,733
Burns	$75,842	$283,441	$46,765	$18,056
Respiratory	$10,600	$224,582	$31,943	$24,789
Combo burn & respiratory	$31,457	$359,579	$85,350	$21,423
Other	$41,646	$339,181	$18,781	$20,841

Footnotes
[1] Adapted from Lawrence et al (2009) [10].

Table 4.5. Calculation of net present value of home fire sprinklers

Parameter	Calculation	Value
P(F)	--	0.0027

Discount rate	--	0.05
Discounting period	--	30 years
Uniform discounting factor, U	**(((1+0.05)^30)-1) / (0.05*((1+0.05)^30))**	**15.372**
Conditional value of injuries with fire alarm only	*P(PAS | DISP | OUTCOME | INJ) * VSI(PAS | DISP | OUTCOME)*	$3,435
Δ_{inj}	--	0.60
Value of injuries averted, V_{inj}	*Overall VSI * Δ_{inj}*	*$2,061*
Probability of death in a home structure fire with fire alarm only, P(Death | Fire)	--	0.0122
Conditional value of medical costs associated with death in a fire, MC_d	--	$353
VSL (2022 dollars)	--	$10,707,290
Δ_{death}	--	0.33
Value of medical costs averted, V_{mc_d}	*MC_D * Δ_{death}*	*$116*
Value of deaths averted	*P(Death | Fire) * Δ_{death} * VSL*	*$43,108*
PVDI	***0.0027 * (2,061+116+43108) * 15.372***	***$1,880***
Climate savings	--	$30
PVCS	***0.0027 * 22.22 * 15.372***	***$1.24***
Average property loss	--	$15,000
PVPL	***0.0027 * 14,570 * 15.372***	***$600***
Average insurance premium	--	$1,600
Average insurance discount	--	0.02
PVI	***(1,614.53 * 0.02) * 15.372***	***$500***
Present value benefits, PVB	***PVDI + PVCS + PVPL + PVI***	***$2,980***
Initial installation cost	--	$13,500
Annual cost of operation & maintenance	--	$13.33
Present value costs, PVC	***10,000 + (13.33*15.372)***	***$13,700***
NET PRESENT VALUE	**PVB – PVC**	**($10,700)**

Table 4.6. Description of the distributions used for Monte Carlo simulations for the sensitivity analyses

Assumption	Distribution	Parameters
P(F)	Triangular	Minimum: 0.0024 Most likely: 0.0027 Maximum: 0.0032
Discount rate	Triangular	Minimum: 0.03 Most likely: 0.05 Maximum: 0.07
Conditional value of injuries with fire alarm only	Discrete	$3,435
Conditional value of medical costs associated with deaths in fires	Discrete	$352
Conditional probability of death in a fire with fire alarm only	Discrete	0.0122
Δ_{inj}	Triangular	Minimum: 0.00 Most likely: 0.60 Maximum: 0.85
Δ_{death}	Triangular	Minimum: 0.00 Most likely: 0.33

		Maximum: 0.91
Value of statistical life (2022 dollars)	Weibull	Mean: $10,707,290 P1: $11,867,247 P2: 1.5096
Climate savings	Discrete	$22.22 per fire
Property loss	Triangular	Minimum: $10,527 Most likely: $14,570 Maximum: $16,775
Insurance premium	Normal	Mean: $1,615 Standard deviation: $173
Insurance discount	Triangular	Minimum: 0.00 Most likely: 0.02 Maximum: 0.10
Cost	Triangular	Minimum: $6,000 Most likely: $13,500 Maximum: $27,500
Annual cost of operation and maintenance	Discrete	$13.33

Table 4.7. Summary statistics of the net present value of benefits in the uncertainty analysis (2022 dollars)

Trials	10,000
Mean	(7,000)
Median	(7,300)
Minimum	(18,000)
Maximum	14,000
Standard deviation	4,100
Standard error	41
95% certainty interval	(14,000) to 1,600

Table 4.8. Breakeven analysis (cost only), holding discount rate constant

Total (per sf)[1] cost,	**Probability that cost will yield a positive net benefit (%)**		
2022 dollars	3% discount rate	5% discount rate	7% discount rate
$500 (0.22)	100%	100%	100%
$1,000 (0.44)	100%	100%	100%
$1,500 (0.67)	99%	99%	99%
$2,000 (0.89)	98%	98%	95%
$2,500 (1.11)	95%	95%	89%
$3,000 (1.33)	96%	90%	81%
$3,500 (1.55)	93%	84%	70%
$4,000 (1.77)	89%	76%	60%
$4,500 (2.00)	84%	68%	50%
$5,000 (2.22)	77%	59%	41%
$5,500 (2.44)	70%	51%	33%
$6,000 (2.66)	64%	44%	26%
$6,500 (2.88)	58%	37%	21%
$7,000 (3.10)	51%	31%	16%
$7,500 (3.33)	45%	25%	12%
$8,000 (3.55)	40%	21%	9%

Footnotes:

[1] sf = square foot of sprinklered area

Table 4.9. Estimated contribution to model variability, holding cost and discount rate constant

Parameter	**Full Monte Carlo Model (%)**	**Breakeven Model (%)**

Δ_{death}	65.8	66.2
Value of statistical life	27.9	26.7
Insurance discount	4.3	5.4
Annual probability of fire	1.5	1.3
Insurance premium	0.4	0.3
Average property loss	0.1	0.1
Δ_{inj}	0.1	0.0

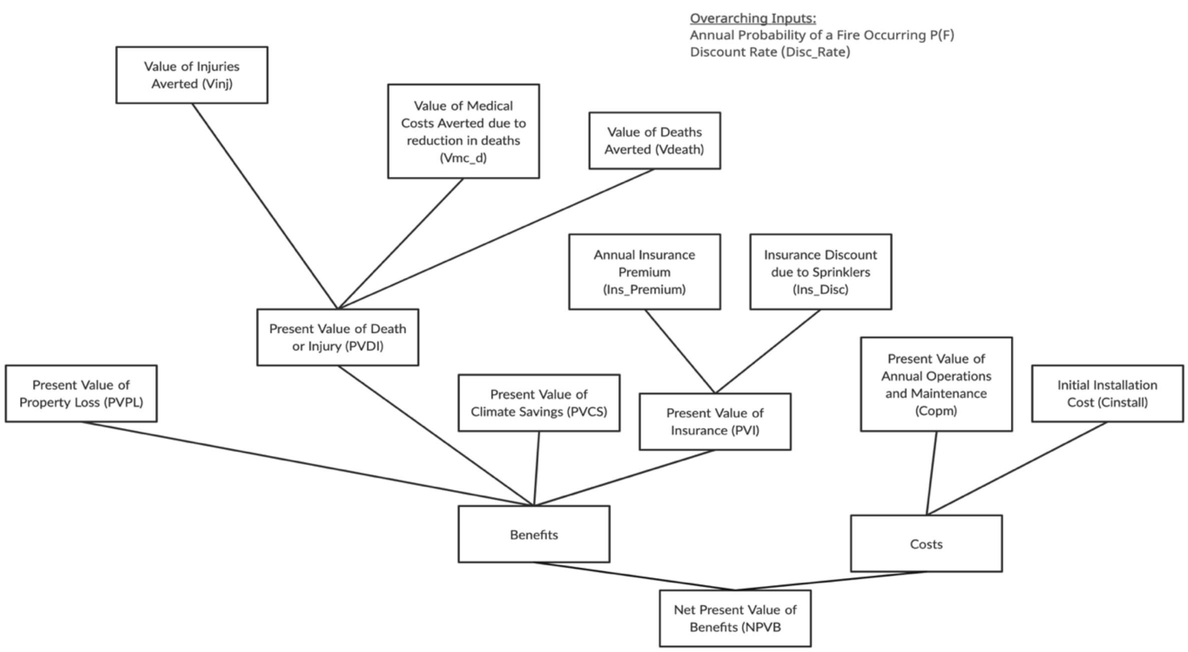
Table 4.10 Comparison of installation costs for home fire sprinklers between 2009 and 2013 FPRF studies with current study (2022 dollars) [1]

	2008 Study [7]		**2013 Study [7]**		**2023 Study**	
	\$/sprinklered ft²	*Total Cost*	*\$/sprinklered ft²*	*Total Cost*	*\$/sprinklered ft²*	*Total Cost*
Mean	\$2.19	\$8,590	\$1.70	\$7,593	\$6.66	\$14,083
Median	\$1.93	\$7,946	\$1.54	\$6,300	\$5.56	\$13,500
Minimum	\$0.52	\$3,245	\$1.02	\$2,126	\$2.40	\$6,000
Maximum	\$4.98	\$21,843	\$3.11	\$26,460	\$13.24	\$27,500

Footnotes

1. Table is the same table as presented in the 2013 NFPA / Newport Partners report, with the addition of results from the current survey [7].

Figure 4.1. Organizational diagram of all inputs for benefit-cost analysis



Chapter 5: Research Article 3

EXECUTIVE SUMMARY: HOME FIRE SPRINKLERS IN NEW ONE- AND TWO-FAMILY HOMES IN MASSACHUSETTS

BACKGROUND

The policy discussion about whether the Board of Building Regulations and Standards (BBRS) should require fire sprinklers in newly-built one- and two-family homes in Massachusetts (MA) has been ongoing for over thirty (30) years. Support for these policies center on the potential reductions in civilian and firefighter injuries and deaths, reductions in property damage, and the economic savings associated with the health and property benefits. Opposition to these policies has mainly been based on an argument that the costs of installation and ongoing maintenance outweigh the value of the benefits. This comparison of benefits and costs has been revisited periodically as new evidence has become available. For example, supporters have recently incorporated benefits associated with reductions in greenhouse gas emissions during fire events and decreases in the amount of water needed to extinguish a fire by a fire department, which had not been previously considered. With pending decisions related to modifications of the MA State Building Code, it is timely to consider the current state of evidence regarding benefits and costs of home fire sprinklers.

The importance of this issue is also potentially increasing over time. In MA, the number of fatal fires in one- and two-family homes has been increasing in recent years, with approximately double the number of fires occurring between January 1 and April 30, 2023 versus the same period in 2022. Multiple factors contribute to this trend, but with more people working from home since the COVID-19 pandemic started, and some evidence of increased risk of fatal fires in more recently constructed housing, the frequency of fatal fires could continue to be higher relative to earlier years.

The question regarding the justification for fire sprinklers in newly-built homes is complicated by the fact that there are multiple potential configurations. When included during initial construction of a home, home fire sprinklers can be configured in a variety of ways to accommodate the individual conditions of the project. These decisions will influence cost as well as logistics regarding installation practices.

POSSIBLE INTERVENTIONS

As the BBRS is currently debating the Tenth Edition of the MA State Building Code, there are three (3) different policy pathways that could possibly be included in the new edition:

1. Continue with only requiring home fire sprinklers in large one- and two-family dwellings (greater than 14,400 square feet) and townhouses, without expanding to all newly-built one- and two-family dwellings;
2. Statewide adoption of mandatory home fire sprinklers for newly-built one- and two-family dwellings; and
3. Adoption of statewide standardized requirements for mandatory home fire sprinklers in newly-built one- and two-family dwellings in communities that choose to adopt them through the home rule process.

Regardless of the pathway chosen for the MA State Building Code, another set of candidate actions would be for the Commonwealth to develop a suite of incentives in order to offset the cost of installation, in addition to those already included in building and fire codes. These could include tax deductions for people building homes with home fire sprinklers and mandatory minimum insurance discounts for homes protected with home fire sprinklers.

Another policy intervention that could reduce the initial construction cost of home fire sprinklers would be to resolve the jurisdictional dispute about which building trade is permitted to install home fire sprinklers (plumbers or sprinkler fitters). By allowing plumbers to install home fire sprinklers, through the issuance of a limited sprinkler fitter license for the installation of multipurpose and passive-purge home fire sprinklers, the number of eligible firms for installing these systems will increase. The increased eligible firms should result in more competitive pricing, compared to the limited elasticity due to the very few number of sprinkler fitting contractors currently installing home fire sprinklers.

BENEFIT / COST IMPLICATIONS

My team and I recently analyzed data from MA to provide the latest evidence for the benefits and costs of home fire sprinklers. The analysis of ten years' data from the MA Fire Incident Reporting System indicated that the presence of home fire sprinklers was associated with a 60% reduction in the odds of civilian injury and a 33% reduction in the odds of civilian death, compared to houses without home fire sprinklers. Though these estimates are very uncertain (due to the small number of one- and two-family homes protected with home fire sprinklers and the small numbers of civilian injuries and deaths during the study period), we also found that these associations were independent of other risk factors evaluated, which included contents of the house, age of the house, fire alarm presence, extent of structural damage, value of property loss, season, and socioeconomic status of the occupants.

My team and I also performed a survey of sprinkler installation contractors in MA, using standardized plans. The results of this survey indicated that the initial installation cost for home fire sprinklers is between $6,000 ($2.66/sf)[1] and $27,500 ($12.19/sf), with an average of $13,500, for a home that is an average of 2,300 square feet.

My team and I combined this information with other types of benefits from home fire sprinklers and determined that the costs of installation more likely than not exceed the benefits, with an average net present value of -$7,000 given current market conditions. The costs and benefits break even when the initial installation costs are between $4,500 ($2.00/sf) and $7,000 ($3.10/sf), depending upon the discount rate used. Using a national study of the health benefits of home fire sprinklers rather than my work in MA, the breakeven point occurs when initial installation costs are between $6,000 ($2.66/sf) and $9,750 ($4.32/sf).

RECOMMENDATIONS

1. The executive and legislative branches of government should work together to develop and implement the suggested incentives to stakeholders to include home fire sprinklers during new construction;
2. The Department of Occupational Licensure should administratively create the abovementioned restricted sprinkler fitter license for licensed plumbers; and
3. The BBRS should include standardized language in the Tenth Edition of the State Building Code to allow municipalities to adopt a local option for the inclusion of home fire sprinklers in newly-built one- and two-family homes.

[1] sf = square foot of sprinklered floor area

1. INTRODUCTION

As of April 30, 2023, the MA State Fire Marshal's office had issued fifteen (15) press releases related to fires in one- and two-family homes since the beginning of the year, twelve (12) of which reported fires resulting in at least one civilian fatality and four (4) of which reported at least one civilian injury. This is more than double the number of press releases during the same time period in 2022 (total of 7 incidents, all of which reported at least one fatality). [1] Records from the MA Department of Fire Services indicate between 12 and 32 civilian fatalities per year (mean = 22, SD = 7) between 2009 and 2021.

The Fire Service community has long advocated for interventions that reduce the odds of fire occurring in residential occupancies. These have included: self-extinguishing cigarettes, mandatory smoke and carbon monoxide detection, and mandatory home fire sprinklers in newly-built one- and two-family homes. Although the successes of converting the first two items into law resulted in significant reductions in the annual probability of fires in one- and two-family homes in recent decades, the overall incidence of fatal fires in one- and two-family dwellings (among those fires that do occur) has increased in recent years. Advocacy efforts for the third intervention, home fire sprinklers, have resulted in requirements for their installation in large residential dwellings (greater than 14,400 square feet) and townhouses, but the Board of Building Regulations and Standards (BBRS), the regulatory body that promulgates the MA State Building Code, has been hesitant to make this a requirement for all newly-built (or substantially renovated) one- and two-family dwellings.

One key question is whether fatal fires more typically occur in older homes or whether the risk would be substantial in newly-built dwellings. In a recent analysis, we found that of the 154 fatal fires between 2009 and 2018 where age of structure was identified 48 (31%) occurred in homes built under the eighth or ninth editions of the MA State Building Code (i.e., since 2011). [2] This is in contrast with earlier findings from the 1995 and 2009 white papers that the BBRS charged its staff to develop. [3, 4] One of the key findings from the 2009 White Paper was that only 20 of the 561 (3.6%) fatal fires between 1986-2005 occurred in homes built after 1975 (the year that Massachusetts first adopted a statewide building code). The two versions of the state building code in effect during my analysis timeframe were based upon editions of the *International Residential Code* that included mandatory home fire sprinkler provisions, which were amended out by the BBRS.

This white paper will focus on three (3) distinct regulatory options for consideration of the BBRS as it is in the process of adopting the tenth edition of the MA State Building Code:

1. Continue with only requiring home fire sprinklers in large one- and two-family dwellings (greater than 14,400 square feet) and townhouses, without expanding to all newly-built one- and two-family dwellings;
2. Statewide adoption of mandatory home fire sprinklers for newly-built one- and two-family dwellings; and
3. Adoption of statewide standardized requirements for mandatory home fire sprinklers in newly-built one- and two-family dwellings in communities that choose to adopt them through the home rule process.

Additional incentives, to be offered in conjunction with whichever regulatory option is selected, should also be considered by policymakers in order to reduce the upfront cost of installing home fire sprinklers in newly-built one- and two-family dwellings. These possible incentives are discussed, in detail, later in this white paper.

1.1 Brief history of home fire sprinklers in the building code

The MA State Building Code has been based upon the *International Residential Code* since the Seventh Edition of the State Building Code. Home fire sprinklers were first adopted in the *International Residential Code* as an optional appendix in the 2006 edition. Following significant advocacy efforts at the national level, the International Code Council converted this into a standalone requirement for all newly-constructed homes built pursuant to the *International Residential Code* in the 2009 edition. It has remained in each of the four subsequent editions to-date.[5] In conjunction with the passage of home fire sprinkler requirements in the *International Residential Code* and in order to incentivize builders to include home fire sprinklers in their projects the following provisions were added to the code:

1. Increased density for homes built with sprinklers, by means of reductions in fire separation distance between non-fire-resistance rated exterior walls;
2. Reduction of the common wall between dwelling units from a 1-hour fire-resistance rating to a 1/2-hour fire-resistance rating;
3. Elimination of the need for providing fire protection on ceilings in unfinished basements;
4. Elimination of the requirement for Emergency Escape and Rescue Openings for sleeping rooms located in basements; and
5. Determination that a habitable attic is not considered a "story above grade" (for building code purposes) if the footprint is less than 50% of the floor area of the story below. [6]

Despite the tradeoffs offered, the BBRS has been reluctant to require home fire sprinklers in all one- and two-family dwellings, primarily because of the findings of the original two white papers developed by their staff. In addition, some stakeholders argue that their inclusion will increase the costs of construction by more than the value of their benefits.[7] The 2009 white paper was written by the One and Two Family Residential Sprinkler Committee of the BBBRS (OTFRSC), and indicates that an important component of the high sprinkler installation cost is labor disputes and water purveyor requirements.

In Massachusetts, supporters of home fire sprinklers initially advocated for adoption of the *International Residential Code* language in the residential provisions of the State Building Code The BBRS has removed these provisions from the State Building Code to-date. As a result, these supporters have been lobbying the state legislature to pass legislation mandating their inclusion for nearly a decade. The legislative approach often follows tragedies, and has resulted in some successes in protection of public safety (e.g., sprinkler protection in existing high-rise buildings, substantially-renovated rooming houses and apartment buildings, and nightclubs). However, there has been limited ability to update the State Building Code as technology and research advance and novel approaches to design and construction methods are developed. At the time that this white paper was prepared, two bills were under consideration by the MA legislature to create a local option for home fire sprinklers, HB 2289 and SB 1552, versions of which have been actively debated for many years (see Appendices B and C for language of these bills).

Currently, the BBRS is considering adoption of the 10th Edition of the MA State Building Code, based upon the 2021 International Family of Codes. The current draft, tentatively scheduled for public hearing in 2023, again amends the *International Residential Code* by removing the provisions for home fire sprinklers. [8] The public hearing process is a forum where any stakeholder is able to provide comments on the proposed state building code, as well as provide potential amendments to the draft prior to submission to the Governor's Executive Office of Administration and Finance. This office reviews the final draft document for factors that include whether the proposed regulations adequately address the Governor's policy priorities. It is than submitted to the Central Register for publication and final promulgation.

1.2 Types of home fire sprinkler systems

Home fire sprinklers, according to the *International Residential Code*, must comply with either NFPA 13D or prescriptive requirements listed in chapter 3 of the *International Residential Code*. NFPA 13D is a life safety standard, the purpose of which is: "to provide a sprinkler system that aids in the detection and control of residential fires and thus provides improved protection against injury and life loss." [9] Home fire sprinkler systems are categorized as either standalone systems or multipurpose systems, both of which have features that affect the degree of maintenance and initial installation costs required. Both types of systems can be interconnected with a house's potable water supply, but standalone systems can also be installed so that they are independent of the potable water supply by installing a pump-and-tank fire sprinkler system. Each of the sprinkler categories can be further classified into specific design types.

1.2.1 Standalone systems

Standalone fire sprinkler systems can be classified as true standalone systems or passive-purge standalone systems. The term "standalone" refers to being standalone from the domestic water distribution system, not the public (or private) water supply. Each of these two categories has its pros and cons. The true standalone system is less complicated to design and install, and has lower up-front costs. This is due to being totally independent of the potable water supply through a pump-and-tank. However, these systems must be inspected and maintained routinely in order to ensure that buildup does not occur from stagnant water in the pipes. True standalone systems that are interconnected to the potable water supply also must have a backflow prevention device installed in order to protect the public water supply. These devices require routine inspection and maintenance as well.

Passive-purge standalone systems are typically connected to the domestic potable water system but are designed in such a way that they are a hybrid of the true standalone system and a multipurpose system. Both the domestic and fire service water come from the same service main entering the house. This service main is typically sized for the fire service. Following the meter, the two services are then separated, with the installation of pressure reducing valves between the higher-pressure fire service and the lower pressure potable water supply piping. In a passive-purge setup, a secondary interconnection occurs near the most remote sprinkler by connecting a single plumbing fixture (often a toilet) to the fire line. This secondary location also requires a pressure reducing valve. The reason for the secondary connection is so that the water in the sprinkler system does not remain stagnant with every flush of the connected toilet, thus significantly reducing the maintenance needs and eliminating the need for a backflow prevention device.

1.2.2 Multipurpose systems

Multipurpose systems are typically categorized as looped or networked systems. In both of these categories, the domestic water supply is branched off of the fire service. The main difference between the two classifications is the layout of the sprinkler piping. A loop is designed and installed as a loop of water flowing through the entire system, while a networked system is comprised of a series of pipes where each head is serviced from multiple directions. The constant flow of water through the system eliminates the need for ongoing maintenance because the opportunity for significant amounts of standing water is eliminated with routine use of the domestic plumbing system.

1.3 Primary stakeholder positions

Supporters

Arguments in support of policies requiring home fire sprinkler installation in newly-built one- and two-family homes center around the life saving effects of home fire sprinklers, as well as their downstream impacts on the public, finances, and environment. These include, but are not limited to: reductions in civilian and fire service injuries and deaths; reduction in property damage; reduction in property tax rates due to decreased workers' compensation claims from fire service members; reduction in water usage when fighting fires; and reductions in toxic gas and greenhouse gas emissions during fire events. In recent years, supporters have increased the literature base documenting these benefits and attempting to quantify their magnitude. [6, 10]

Opponents

Points raised in opposition to policies requiring home fire sprinklers typically fall into two categories: cost (initial installation and ongoing maintenance) and the value of benefits. While opponents do not deny the benefits listed by supporters, they contend that the magnitude of benefits is small and also point to uncertainty in the estimates.

1.4 Key stakeholder organizations

Below are key stakeholders who either support, oppose, or are neutral toward the BBRS adopting home fire sprinklers in the State Building Code. This list is not exhaustive of all stakeholders, as other groups (e.g., the National Fire Sprinkler Association and National Fire Protection Association) are vocal about their positions relative to home fire sprinklers, but their interests are incorporated into those key organizations listed below. In addition, the BBRS is not listed as a key stakeholder organization, as they are the public policymaking / decision-making body who develops and interprets the State Building Code.

Supporters

Fire Chiefs' Association of MA (FCAM): FCAM primarily represents the chief fire officers of municipalities across the Commonwealth, although its approximate 900-person membership includes a large swath of professions whose interest aligns with FCAM's mission. According to their website, their mission is to: "further the professional advancement of the fire service; serve as the recognized Fire Chiefs' organization for the exchange of ideas, knowledge and experience in the area affecting fire prevention, fire extinguishment, and the safety of life and property from fire; and promote efficient fire administration."[11] FCAM has been the primary proponent of legislation supporting the adoption of home fire sprinklers in MA. It is the official state affiliate of the International Association of Fire Chiefs.

Fire Prevention Association of MA (FPAM): Founded in 1974, FPAM represents all of the members of the fire service (active and retired) who are involved in fire protection. Their approximate 500-person membership of fire prevention officers also includes associate members who support fire prevention efforts in MA.

Sprinkler Fitters Local 550 (Local 550): The Sprinkler Fitters Union represents, and trains, sprinkler fitters in the Commonwealth. [12] Given their focus on fire sprinkler systems, Local 550 has been the principal author (and proponent) of multiple pieces of legislation relative to home fire sprinklers in the past decade.

Professional Fire Fighters of Massachusetts (PFFM): The PFFM is the state affiliate of the International Association of Fire Fighters (IAFF), which represents over 12,000 active and retired paid firefighters, EMTs, and paramedics across the Commonwealth. [13] Although many of their advocacy efforts and legislative priorities focus on firefighter safety and protection, they have historically been supporters of legislative efforts promoting home fire sprinklers, but have been silent on their position relative to the current proposed legislation.

Opponents

Home Builders & Remodelers Association of MA (HBRAMA): According to its website, HBRAMA "is a non-profit trade association consisting of over 2,000 single and multi-family builders, developers, remodelers, suppliers and other allied professionals to the residential construction industry". [14] It is the state affiliate for the National Association of Home Builders, and is comprised of representatives of five affiliate local associations throughout the Commonwealth. The home building industry has been the primary opponent to efforts to mandate home fire sprinklers at both the national and state levels. [7]

Neutral

MA Federation of Building Officials (MFBO): The MFBO is a non-profit professional association comprised of representatives from the four (4) affiliate professional associations representing building officials (building inspectors and commissioners) across the Commonwealth. [15] The MFBO was previously an opponent of home fire sprinklers, but recent shifts in their leadership have resulted in an overall neutral position. They are strong opponents of creation of building code requirements through legislation and are on-the-record of supporting the code adoption process of the BBRS.

Unknown

Insurance: The insurance industry's position relative to requirements of home fire sprinklers varies, depending upon their actuarial data. The rates for homeowners' insurance are partially based upon Public Protection Classification (PPC) and Building Code Effectiveness Grading Schedule (BSCGS) results published by the Insurance Service Office (ISO), the latter of which grades local building departments on their staffing levels and deviation of the adopted building code from the model building codes developed by the International Code Council. [16, 17] The insurance industry has a very strong presence at the code hearings of the various standard-setting organizations, and regularly participates in the debates, but the industry's position on home fire sprinklers in MA is not known.

Water purveyors: American Water Works Association (AWWA) published a 38-page guidance document for its members regarding residential fire sprinkler systems in 2018. [18] This document provides water purveyors with an overview of residential fire sprinkler systems (home fire sprinklers) and the various installation requirements for these systems. One major concern of water purveyors, historically, has been backflow of potentially contaminated water from the fire sprinkler system into the domestic water supply. As a result, many historically required the installation of backflow prevention devices. The AWWA document clearly describes the various configurations that require these backflow prevention devices, as well as configurations that do not so require.

1.5 Relevant legal history

MA State Building Code

The Commonwealth of Massachusetts adopted a statewide building code following the passage of Chapter 802 of the Acts of 1972, which also created a statewide Building Code Council to oversee the development of the statewide building code. [19] The first edition of the statewide building code (780 CMR) was promulgated on January 1, 1975. It was quickly followed by a second edition a few months later, with subsequent editions being adopted periodically as needed. [5] 780 CMR is currently in the ninth edition, with changes for the tenth edition currently under review by the BBRS.

The issue of fire safety has been addressed by 780 CMR since its inception, but two major challenges that the fire service faces are that the code is for new construction and municipalities cannot adopt their own local amendments without prior approval from the BBRS. This limits the ability of the building official to apply new safety standards retroactively or municipality by municipality. To counter this, the fire service has worked closely with the legislature to address major fire safety concerns that must be applied retroactively for which there is no approach under the current statewide building code.

Advocacy efforts to include home fire sprinklers in the residential provisions of 780 CMR date back decades for advocates for fire safety. These concerns have been heard by the BBRS, but were ultimately not adopted into the code to-date. This has left advocates with only one remaining tool, legislation. The challenges of legislating building code have been previously addressed in this white paper, but the advocates continue to file the legislation in their effort to protect lives across the Commonwealth.

Division of labor

One of the major sources of resistance to home fire sprinklers stems from both the logistical and cost implications of uncertainty regarding which building trade(s) can install home fire sprinklers. According to MGL Chapter 142, Section 1, plumbing is defined as:

> "the work and practice, materials and fixtures used in the installation, removal, maintenance, extension, and alteration of a plumbing system; of all piping, fixtures, fixed appliances, and appurtenances in connection with any of the following: sanitary drainage, storm drainage facilities, special wastes, the venting system and the public or private water-supply systems, within or adjacent to any building, structure, or conveyance; to their connection with any point of public disposal or other acceptable terminal within the property line." [20]

In contrast to the definition of plumbing, the definition of a fire protection sprinkler system, which only a fire protection sprinkler system contractor can install, alter, modify, test, inspect, maintain, repair, or remove, was defined as the following until April 2, 2023:

> "a fire sprinkler system, for fire protection purposes, the work of the sprinkler fitter and apprentice shall consist of the installation, service, testing, maintenance and inspection of all fire protection and fire control systems, including both overhead and underground water mains, fire hydrants and hydrant mains,

> standpipes and hose connections to sprinkler systems, sprinkler tank heaters, air lines and thermal systems, hot water fire protection systems and standpipes connected to sprinkler systems." [21]

Effective April 2, 2023, the above definition was modified by adding "and pumps dedicated for fire protection" to the end of the definition through Chapter 357, Section 1, of the Acts of 2022. [21]

The dispute between the trades stems from their interpretation of each of these definitions. Plumbers feel that they should be permitted to install the entire system, if constructed in a multipurpose or passive-purge configuration. Sprinkler fitters feel that they should install the sprinkler portions and have plumbers only install those portions that branch off of the sprinkler system to the plumbing fixtures. Previous attempts to reconcile the differences have not been successful.

The MA Board of State Examiners of Plumbers and Gas Fitters (Plumbing Board) released a policy on December 7, 2017, on their website, addressing their opinion about who has authority to install which components of the home fire sprinkler system. [22] The Plumbing Board argues that since "the installation of these Systems by definition includes direct connection of sprinkler heads to potable water piping, and thus the entire System including the sprinkler head must be installed by a licensed plumber". They then state that "the Board recognizes that DPS has taken the position that sprinkler heads attached to a potable water supply must be installed by a licensed sprinkler fitter. However, the Board reiterates that only a licensed plumber may install a potable water system or any fixtures directly connected to said system".

The Plumbing Board's policy statement was written when Sprinkler Fitters were regulated by the MA Department of Public Safety, which no longer exists. The licensure of both sprinkler fitters and plumbers is now regulated by the MA Department of Occupational Licensure (DOL), which is also charged with developing standards for licensure and apprenticeship of both trades. This leads to the hope that these conflicts between the appropriate jurisdiction and licensing requirements can be resolved internally by the DOL. There are multiple possible approaches to finding this resolution, which are described in detail in the regulatory interventions section of this white paper.

2. REVIEW OF THE EVIDENCE

2.1 Effectiveness of home fire sprinklers

The literature evaluating the effectiveness of home fire sprinklers in reducing civilian injuries and deaths is very limited. Data from the National Fire Protection Association (NFPA) indicates that sprinklers reduce the rate of civilian deaths and injuries by 88 and 28 percent, respectively, without providing confidence intervals. [23] My analysis of data from the MA Fire Incident Reporting System between 2009-2018 examined a total of 13,867 structure fires using multivariable analysis, which indicated that presence of home fire sprinklers was associated with a 60% reduction in the odds of civilian injury (OR = 0.40, 95% CI: 0.15-1.12) and a 33% reduction in the odds of civilian death (OR = 0.67, 95% CI: 0.09-5.13) compared to houses without home fire sprinklers. [2]

This analysis suggests that home fire sprinklers may reduce civilian injuries and deaths in one- and two-family homes, compared to similar homes without home fire sprinklers, though the estimates have very wide confidence intervals given the small numbers of civilian injuries and deaths even in a 10-year study period. We also found that these associations were independent of other risk factors evaluated, which included contents of the house, age of the house, fire alarm presence, extent of structural damage, value of property loss, season, whether any human factors contributed to the fire's ignition, and socioeconomic status.

2.2 Benefit-cost analysis

Previous benefit-cost analyses by both the NFPA and the National Institute of Standards and Technology (NIST) have consistently shown that the financial benefits associated with the installation of home fire sprinklers outweigh the costs. [23-27] In 2017, researchers at the University of Nevada, Las Vegas, released a cost-benefit analysis for the Las Vegas Fire and Rescue Department that argued that use of cost is the wrong metric and is a "red herring" in the discussion about the possible benefits of home fire sprinklers, and that the discussions should center around the effects of these systems on life safety. [28]

My team and I performed a benefit-cost analysis of home fire sprinklers that added to the evidence provided by NFPA and NIST. Some additional features that the benefit-cost analysis addressed included updating the earlier analyses with MA-specific data as well as expanding the uncertainty analysis and including some pathways omitted previously (e.g., greenhouse gas emissions). As part of the analysis, we performed a breakeven analysis in order to determine at what installation cost it is more likely than not that the benefits would be greater than the costs.

The analysis indicated an average net present value of home fire sprinklers of -$7,000 (95% certainty interval: -$14,000 to $1,600), indicating that the costs more likely than not exceed the benefits. The results can be interpreted as saying that (on average) the costs would be $7,000 greater than the benefits, but that we are 95% confident that the real estimate is between costs outweighing benefits by $14,000 and benefits outweighing costs by $1,600. Average breakeven points for total installation cost were between $4,500 ($2.00/sf)[2] and $7,000 ($3.10/sf) depending upon the discount rate.

We then performed the same analysis using the NFPA estimate for effectiveness of home fire sprinklers in reducing deaths instead of the one we developed, and the net present value increased to -$5,000 with a 95% certainty interval of -$13,000 to $5,000. The breakeven points also increased to installation costs between $6,000 ($2.66/sf) to $9,750 ($4.32/sf) depending upon the discount rate applied. The breakeven estimates for installation costs using the NFPA estimate appear within the range of installation costs we found in the survey of sprinkler installers ($6,000 ($2.66/sf) to $27,500 ($12.19/sf) with an average of $13,500 ($5.99/sf) for a home that is an average of 2,300 square feet). The breakeven estimates using estimates in MA were largely outside of that range.

2.3 Under-reporting of fires in homes

Beyond the statistical uncertainty my team and I quantified in our benefit-cost analyses, there are other dimensions of uncertainty that are important to consider. For example, conclusions about the potential benefits of home fire sprinklers, specifically as they relate to reductions in damage to a home following a fire, are likely underestimates of the true benefits. This is because recent research has shown that the number of home fires attended by the fire service is likely only a fraction of the actual of number of fires that occur in one- and two-family homes. [29, 30] Estimates for the degree of un-reported fire events range from 84 to 97 percent of the actual number of fires occurring in residential occupancies being unattended by the fire service. Although one could argue

[2] sf = square foot of sprinklered floor area

that the large majority of unattended fires are likely small, we are not aware of any studies that assess the resultant property loss associated with these fires.

Given that some of these fires could be extinguished by a home fire sprinkler faster than by other means, a reasonable person could argue that the value of the property loss could have been reduced had the property been protected with home fire sprinklers. The property loss savings at the individual incident-level are likely small. However, if the estimates for large numbers of unreported fire events are accurate, the cumulative unreported property loss savings may be appreciable.

3. POSSIBLE SCENARIOS

3.1 Do nothing

This scenario is to maintain the status quo of the building code, as it is in its current form. Home fire sprinklers would only be required in large single- and two-family homes and all townhouses.

3.2 Statewide adoption

Statewide adoption would require promulgation of the IRC provisions in the State Building Code, without amendment. This would result in all newly-built one- and two-family homes in Massachusetts being required to have home fire sprinklers installed. This would also eliminate the need for advocacy and lobbying efforts by proponents to require home fire sprinklers through legislation.

3.3 Local option adoption

Local option adoption can follow a similar format to the way the “stretch” energy provisions were originally adopted in MA. In that case, the BBRS promulgated optional “stretch” provisions that towns could adopt, as they felt appropriate, through their municipal rulemaking processes. This allowed for a uniform standard across the Commonwealth, while also giving municipalities the flexibility to provide for enhanced fire protection. Without creation of standardized local option language in the building code itself, municipalities are preempted from adopting their own local building codes, without prior approval by the BBRS, by M.G.L. Chapter 143, Section 98. [31]

In addition to the "stretch" energy code, the fire service previously used legislation to provide local option adoption for retrofitting fire sprinklers in certain occupancies through M.G.L. Chapter 148, Sections 26G, 26H, and 26I (non-residential structures greater than 7500 square feet, rooming and boarding houses, and multi-family residential structures that are substantially repaired and have 4 or more dwelling units, respectively). Following many years of successful local adoption of Section 26G, the provision was expanded statewide.

4. BARRIERS TO ADOPTION OF HOME FIRE SPRINKLER REQUIREMENTS

4.1 Labor issues

The primary barrier to adoption of home fire sprinkler requirements is cost. My team recently conducted a survey of fire sprinkler contractors in order to obtain a reliable estimate for installation costs of standardized designs. Upon reviewing the websites of nearly twenty (20) fire sprinkler contractors across MA, we were able to identify seven (7) who listed residential installations as services they offered. Of these, three (3) reported that they have not installed any home fire sprinkler systems in the past two (2) years.

It could be argued that the paucity of fire sprinkler contractors installing home fire sprinklers is a result of lack of demand for such services. I believe that if home fire sprinklers were required in the State Building Code, it would increase demand and then the number of contractors in the field and, ultimately, reduce the cost.

Currently, installation of home fire sprinklers is not included in the training of plumbers in MA, but the creation of a specialty category of sprinkler fitter licensing has been previously proposed to allow plumbers to install these systems after proper training. The National Fire Sprinkler Association, one of the professional associations assisting the sprinkler fitting industry, offers a 32-hour course to train sprinkler fitters and plumbers on the installation of home fire sprinklers that meet the requirements of the *International Residential Code*. Neighboring states, like Connecticut, allow for the use of this training in order to meet the demand needs for home fire sprinkler installations.

The previously-mentioned reorganization of the Bureau of Pipefitters, Refrigetration Technicians, and Sprinkler Fitters provides an opportunity to eliminate some of the conflict between these trades and the plumbers by finding a mutually-agreeable compromise. Such a compromise could increase the number of skilled tradespeople available to install home fire sprinklers and reduce the number of building trades that a developer (or general contractor) must hire in order to build a single- or two-family home. A potentially feasible solution could include creation of the specialty sprinkler fitting license for plumbers to install home fire sprinkler systems while also providing licensed sprinkler fitters a pathway toward plumbing licensure. This pathway toward plumbing licensure might be in the form of offering to count an active sprinkler fitting license toward one year of plumbing apprenticeship.

4.2 Statistically significant effectiveness estimates

The estimate of the effectiveness of home fire sprinklers for civilian injuries and deaths in MA had a wide confidence interval in my analysis. This is due to: 1) the small number of homes protected with home fire sprinklers, 2) the relatively low probability of a fire in a one- or two-family home in MA, and 3) the relatively low probability of any civilian injuries or deaths following fires in one- and two-family homes in MA. It is not easy to reduce this statistical uncertainty, but the availability of analysis-ready datasets for more years in MA or national-scale datasets with sufficiently robust data could allow for more accurate estimates.

5. POSSIBLE INCENTIVES TO INSTALL HOME FIRE SPRINKLERS

In 2010, the NFPA's Fire Protection Research Foundation published a report on potential incentives that can be offered in order to increase home fire sprinkler installations. [32] This report considered three different levels of incentives that could be offered for the inclusion of home fire sprinklers, many of which have already been incorporated into the *International Residential Code* and *International Fire Code*, as well as NFPA 1: *National Fire Code*. They included reductions in fire separation distances, permission to use different construction types, increasing the number of openings in sprinkler-protected buildings, the length of cul-de-sacs, and the distance between fire hydrants. Additional potential incentives included reductions in permitting fees and / or property taxes.

Given that the homebuilding community has historically been a vocal opponent of home sprinklers, an incentive-based approach that reduces the financial barriers for homebuilders might be effective. These incentives could include a state tax deduction for the party financing the construction of homes built with home fire sprinklers of a magnitude (e.g., $5,000 per house) that would at least partially offset the costs of their inclusion in the construction of the house.

One final possible incentive that could be considered is mandating that homeowners insurance companies provide a minimum discount (e.g., 5-8 percent) off of the homeowners insurance premium for homes protected with a code-compliant home fire sprinkler system. My review of current discounts offered by homeowners insurance companies in MA varied widely, with values ranging from 0 to 10 percent, with an average of 2% discount. Many of the higher percentage discounts were offered only for systems that are monitored and/or provided attic sprinkler protection. A discount of 5-8 percent on homeowners insurance policies, for homes protected with home fire sprinklers, is not unprecendented in MA, as a 2008 study by the NFPA's Fire Protection Research Foundation found that the discount among the top 5 homeowners insurance providers in MA was between 5-10 percent, with an average of 7 percent.

6. CONCLUSIONS / RECOMMENDATIONS

My recent benefit-cost analysis indicated that the costs of installing a home fire sprinkler more likely than not outweigh the benefits given current costs and estimates of the health benefits of sprinklers. However, policy measures that reduce the cost of installation would alter the benefit-cost calculus. This shift might be achieved by addressing the labor dispute about who has the authority to install home fire sprinklers. Allowing plumbers to install certain 13D systems eliminates the need to bring in an additional trade for a relatively small portion of the project. The setup time and coordination required for contracting with two separate trades working on different components of the same project increases costs. In addition, costs can be reduced by utilitizing the passive purge design, which appears to be the most cost-effective layout. This approach nearly eliminates the ongoing maintenance requirements for the home fire sprinkler system and eliminates the need for backflow protection while providing the benefits of a standalone sprinkler system.

In order to maximize the stakeholders who are satisfied with the compromise, policymakers should consider the following items when deciding which of the three possible scenarios to implement:

1. Addressing the question of who can install home fire sprinklers;
2. Developing a suite of incentives that can garner support from the homebuilding community (e.g., tax deduction for projects that include home fire sprinklers);
3. Standardizing a minimum discount on homeowners insurance premiums for homes protected with home fire sprinklers; and
4. Addressing gaps in the data to arrive at evidence-based decisions.

As mentioned earlier, building codes are often reactive instead of proactive. This has been shown to be especially true in the domain of life safety systems, primarily because they are often associated with an increased cost for construction (and often also come with ongoing maintenance requirements).

As was a successful strategy to improve energy efficiency in new construction in MA, an incremental approach to mandatory home fire sprinklers is recommended. In order to do this, a standardized local option is recommended for adoption in the 10th Edition of the State Building Code (similar to the promulgation of the "stretch" energy code). The "stretch code" model and the upcoming "net zero code" model allow individual communities to opt to be more energy efficient than the baseline statewide energy code. Similarly, a local option home fire sprinkler provision would give individual communities that ability to mandate home fire sprinklers while also having the process standardized by the Commonwealth. This incremental approach should be paired with a series of statewide incentives that offset the cost of installing home fire sprinklers for those affected.

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Chapter 6: Summary, discussion, and future implications

1. Introduction

The Massachusetts boards who regulation construction and trade activity are considered legislative (or political) in nature, and are not required to consider the evidence base when making policy decisions.[1] The Massachusetts Board of Building Regulations and Standards ("BBRS"), in particular, is comprised of representatives of various impacted stakeholder groups and is one of the few without a representative of the general public.[2] Often, the only people who testify at the code-change public hearings are members of the various stakeholder groups represented by the board members. This can lead to decisions by the board that benefit the most stakeholder groups, instead of the best interest of life safety.

One recurring example of this problem is the case of fire sprinklers in newly-built one- and two-family homes ("home fire sprinklers"). Home fire sprinklers have been required by the consensus-based international model code, upon which the BBRS bases the MA State Building Code.[3, 4] Regardless of their inclusion in the international model standard, the BBRS has actively removed these requirements in every edition of the State Building Code, to-date; including the draft tenth edition for which a public hearing is planned for late-2023.[5, 6]

Previous benefit-cost analyses have been based upon incomplete national data and included unrealistic estimates for certain parameters.[7-11] Many of these challenges were identified in white papers commissioned by the members of the BBRS over a decade ago.[12, 13]. Opponents to these measures have continually used these limitations in the literature to challenge home fire sprinkler provisions in the MA State Building Code, as well as across the nation.[14]

This dissertation attempts to address each of the previous limitations in a systematic manner. In order to address concerns of data quality and integrity in the National Fire Incident Reporting System ("NFIRS"), we based our analyses on the state-specific Massachusetts Fire Incident Reporting System ("MFIRS").[15, 16] This database provided us with a robust amount of data, with reporting from over 95% of the fire departments in the Commonwealth of Massachusetts.[16] The strength of this database comes from the fact that reporting is mandated by the Massachusetts General Laws, and departments are further incentivized to report their data because state-administered funding is connected to participation in the system.[17, 18]

2. Summary of specific aims and results

2.1 Specific Aim #1

To our knowledge, our effectiveness study (Chapter 3) was the first such article to assess both the univariate effectiveness of home fire sprinklers on civilian injuries and deaths following a fire incident in a one- or two-family home and the multivariable effectiveness of home fire sprinklers and a number of other parameters suspected of having an influence on civilian injuries and deaths. These included: fire alarm presence (primarily single- and multiple-station smoke detectors), contents contributing most to fire spread, extent of fire spread, presence of human factors leading to ignition, value of property loss, property value, season, and socioeconomic status of the census block. In addition, our study was the first to assess the relationship between building code edition in effect at time of initial construction and civilian injuries and deaths following a fire incident in a one- or two-family home. This study was also the first such study to evaluate the degree of multicollinearity between each of these parameters.

In our univariable analysis, the presence of home fire sprinklers was associated with a 61% reduction in the odds of a civilian being injured (OR = 0.39, 95% CI: 0.15-1.06, p = 0.06) and a 52% reduction in the odds of a civilian death (OR = 0.48, 95% CI: 0.07-3.45, p = 0.46) compared to homes without home fire sprinklers. Following multivariable analysis, presence of home fire sprinklers was associated with a 60% reduction in the odds of civilian injuries (OR = 0.40, 95% CI: 0.15-1.12, p = 0.08) and a 33% reduced odds of civilian death (OR = 0.67, 95% CI: 0.09-5.13, p = 0.70) compared to homes without home fire sprinklers. These odds of civilian death was strongly influenced by the association between presence of home fire sprinklers and presence of human factors prior to ignition, where the Odds Ratio would be 0.85 (95% CI: 0.11—6.37) if human factors were excluded from the model. The maximum variance inflation for each of the outcomes was 1.4, indicating no multicollinearity between the parameters in the multivariable models. We also used only observations with complete data, which (although it reduced the total sample size) resulted in tighter confidence intervals about the parameters of interest. Estimates from the multivariable analysis indicate that the presence of home fire sprinklers would have spared 44 civilian injuries (95% CI: 8 to 80) per 1,000 fire incidents, and 4 civilian fatalities (95% CI: -15 to 23) per 1,000 fire incidents in one- and two-family homes in Massachusetts.

2.2 Specific Aim #2

Our benefit-cost analysis (Chapter 4) updated previous benefit-cost analyses with data from an individual state (Massachusetts) with robust input data. We addressed the concerns raised in the original BBRS-commissioned white papers by improving the evidence base, and methodology used in performing the benefit-cost analysis in a number of ways. We created and implemented a survey to determine installation costs in Massachusetts. This was performed using a standardized set of plans and survey instrument for participating companies to complete. We asked participants about profit markup in their costs, as previous installation cost estimates only reported cost to the contractor and not final cost to the end-user.

We also updated homeowners' insurance discount data, which was last reported in 2008. Given the many changes in annual probability of a fire occurring in one- and two-family homes in Massachusetts, the 2008 data was considered outdated. Our survey included data from nine of the ten insurance carriers with greatest market share in Massachusetts, compared to the top 5 in the 2008 survey.

Our study was the first benefit-cost analysis to incorporate the value of environmental savings associated with the presence of home fire sprinklers. We used the social value of carbon as the basis for this estimate, combined with data reported by researchers at FM Global.[19]

This study was the first benefit-cost analysis for home fire sprinklers to assess the potential savings associated with reductions in civilian injuries and deaths using granular data that combined the proportional probability of a particular outcome with the cost associated with that specific outcome. Previous studies used an overall cost estimate. These estimates were also adjusted to 2022 dollars.

This study was also the first to comprehensively evaluate the effect of uncertainty on estimates for net present value of benefits. Previous studies, from the National

Institute of Standards and Technology ("NIST") assessed limited amounts of uncertainty in their monte carlo distributions, but did not include uncertainty around many important variables (e.g., value of statistical life, discount rate applied to the policy decision, amount of insurance discount, annual insurance premium, and installation cost).[8, 10]

Finally, this analysis is the first benefit-cost analysis for home fire sprinklers to determine breakeven points between benefits and costs, stratified by discount rate applied to the analysis. Previous studies used a 3% discount rate, but the United States Office of Management and Budget requires that federal agencies provide benefit-cost analyses using both a 3% and 7% discount rate for certain policy considerations.[8, 10, 20] Providing the breakeven points, stratified by discount rate, helps policymakers determine whether a policy decision is feasible, given certain present (and expected) economic conditions.

We found that home fire sprinklers have an average net present value benefit of -$7,000 (95% certainty interval: -$14,000, $1,600) following uncertainty analysis using a Monte Carlo distribution. Breakeven analysis indicated a ≥ 50% probability of a positive net present value when overall initial installation costs are between $4,500 and $7,000, depending upon the applicable discount rate. Uncertainty around cost accounted for 56.0% of the variability in the full Monte Carlo model. We also found that uncertainty around the effectiveness of home fire sprinklers on reducing the number of civilian deaths following fire incidents in one- and two-family homes in Massachusetts accounted for 65.8% of the variability in the full Monte Carlo model and 66.2% of the variability in the breakeven model, when holding host and discount rate constant.

2.3 Specific Aim #3

We developed a comprehensive policy paper, to be provided to the BBRS prior to the public hearings for the tenth edition of the Massachusetts State Building Code, that provides detailed analysis on the question of whether they should include home fire sprinkler provisions in the upcoming tenth edition of the Massachusetts State Building Code. This paper also provided both an analytical framework for the members of the BBRS to use when considering the home fire sprinkler provisions, as well as a recommendation as to the final policy decision to include in the tenth edition of the Massachusetts State Building Code.

Unlike the BBRS-commissioned white papers on the topic, this policy paper included a detailed history of the policy decision, a listing of three possible intervention scenarios, a review of the evidence base, discussion about the benefit / cost of each of the possible scenarios, a stakeholder analysis, barriers to adoption of the home fire sprinkler requirements, and possible incentives to consider if choosing to adopt the home fire sprinkler requirements. This policy paper will provide the members of the BBRS, and any other policymaker in the Massachusetts administration who has a role in deciding whether home fire sprinklers should be required in Massachusetts, a comprehensive overview of the policy decision before them; as well as a roadmap to making their final decision.

3. Public health implications

3.1 Effectiveness of home fire sprinklers

Our results suggest that home fire sprinklers are associated with reduced odds of civilian injuries in single- and two-family homes in Massachusetts. These associations were independent of associations between this outcome and the other risk factors for civilian injury or death commonly cited in the literature (fire alarm presence, building contents, age of structure, property value, presence of human factors leading up to ignition, and fire spread), although our results had very wide confidence intervals. The use of 10 years' worth of comprehensive fire reporting data increased our ability to evaluate the above associations and have more comfort that the data lacked selection bias. These data also allowed us to analyze data from relatively infrequent events (fires occurring in one- and two-family homes in Massachusetts) and begin to draw conclusions from these analyses.

3.2 Benefit-cost analysis of home fire sprinklers

Our analysis indicates that the net present value of benefits ("NPVB") for home fire sprinklers is -$7,000 (95% CI: -$14,000 - $1,600). We also performed a breakeven analysis that found a greater than 50% probability of a positive NPVB when the initial installation cost was between $4,500 ($2.00/sf) and $7,000 ($3.10/sf), depending upon discount rate applied. Our policy paper (Chapter 5) then combined these results with the current policy landscape (in Massachusetts) to provide a framework for policymakers to make a determination whether home fire sprinklers should be required in newly-built one- and two-family homes in Massachusetts. This framework provides for an incremental approach to expanding the prevalence of home fire sprinklers in one- and two-family homes, which may result in fewer civilian injuries or deaths following fire events such homes.

4. Limitations and directions for future research

The literature base prior to our research was very small and based upon data of questionable quality. Previous analyses did not report uncertainty in the central estimates for the effectiveness of home fire sprinklers in preventing civilian injuries and deaths in one- and two-family homes. Our use of 10-years' worth of data permitted us the ability to perform the analysis of the associations between rare exposures (presence of home fire sprinklers in one- and two-family homes) and rare outcomes (civilian injuries and deaths). These associations still resulted in odds ratios with wide confidence intervals, indicating a large degree of uncertainty about the estimates. As noted in Chapter 3, in order for the estimates for effectiveness in preventing civilian deaths to have sufficient statistical power, approximately 1.15 million incidents would need to be included in the dataset (which is 83-times the number of incidents included in our dataset, N=13,867).

Further, other factors presumed to be associated with the odds of civilian injuries and deaths following unconfined structure fires in one- and two-family homes could not be assessed due to lack of sufficient data. These included age and sex of the person(s) involved, which were not provided due to privacy concerns. We performed univariate analyses for 11 possible covariates, and then developed a parsimonious model that assessed the impact of each of these covariates on a final multivariable model. The covariates included in the final multivariable model described 74% of the variability in civilian injuries and 88.7% of the variability in civilian deaths in the respective models.

Uncertainty was central to the benefit-cost analysis (Chapter 4), as illustrated in Table 9: estimated contribution to model variability, holding cost and discount rate constant. Uncertainty surrounding the odds of presence on home fire sprinklers reducing civilian deaths accounted for 65.8% of the variability in the full Monte Carlo model and 66.2% of the variability in the breakeven model. In addition, uncertainty about the value of statistical life accounted for 27.9% of the variability in the full Monte Carlo model and 26.7% in the breakeven model. These then resulted in wide certainty intervals for estimates of the NPVB and breakeven point where the value of the benefits are greater than the value of costs.

The current dataset provides insight into possible associations between civilian injuries and deaths and a number of covariates, but more data are needed in order to draw statistically-significant inferences. With the current prevalence of home fire sprinklers, this would require a different approach to the analyses, which may result in other forms of uncertainty. One such approach includes combining data from other states, although issues have been raised relative to the quality of data reported from other states.[15] Another approach is to include more years' worth of data, which could result in inconsistencies if those data were collected using different methods (e.g., different editions of the questionnaire).

The policy paper (Chapter 5) lists a number of possible interventions and approaches that policymakers can implement. This provides an opportunity to assess the possible impact of any of these interventions on civilian injuries and deaths, using our analysis as a baseline for such analyses.

5. Conclusion

This dissertation sought to provide a robust analysis of a complex building code provision, as evidence for policymakers to utilize when deciding whether to include a specific provision in the next edition of the Massachusetts State Building Code. In addition to providing empirical evidence relative to the effectiveness and benefit-cost of the proposed building code provision, this dissertation included a detailed analysis of considerations for policymakers to consider. These included: a detailed description of the policy item being considered, the legal (and legislative) history of the policy topic, a detailed stakeholder analysis, a review of the evidence, multiple possible scenarios (and analysis of their possible implications), barriers to certain interventions, and possible incentives to consider as part of the policy decision.

The case of home fire sprinklers was the ideal testing ground for this approach to building code-related policy decisions. This is because it follows multiple decades of heated debate from stakeholders on both sides of the issue, with little empirical evidence (and strong emotions) that served as the context for policymakers to consider. We used a clear methodology for every aspect of the empirical analyses, which incorporated the various arguments presented by stakeholders both in support and opposition of home fire sprinklers.

Our findings suggest that a cautious approach to requiring home fire sprinklers in newly-built one- and two-family homes must be followed. We recommended that a local-option approach be adopted by the BBRS, similar to the Stretch Energy Code, combined with various incentives aimed at reducing the initial installation cost of home fire sprinklers. The coalescence of the three specific aims of this dissertation resulted in a thorough basis upon which policymakers can rely when deciding whether home fire sprinklers should be required in Massachusetts.

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Chapter 8: Appendices

Appendix A: Survey / interview guide

By Felix I Zemel, MPH, DrPH Candidate – Tufts University School of Medicine

Good afternoon.

My name is Felix Zemel and I am a graduate student at Tufts University School of Medicine. I am working toward my Doctor of Public Health degree, where my dissertation is looking into various policy considerations relative to home fire sprinklers in newly-constructed one- and two-family dwellings in Massachusetts.

A vital part of my dissertation is evaluating the economics of home fire sprinklers in MA. For this portion of the work, I would like to obtain local data specific to MA.

I am attaching floor plans for the three prototypical homes that NIST used in their cost estimates in 2005. These are a 3,338 SF Colonial, a 2,257 SF Duplex, and a 1,171 SF Ranch.

Can you please answer the following questions as if these homes were located in: Lowell, Boston, Worcester, and Springfield, MA:

1. For these homes, what type of home fire sprinkler system does your firm typically install (standalone, networked / multipurpose, etc)?
2. If the firm typically installs a standalone system, would a backflow preventer be installed as well?
3. What is the total cost of the system in each of the prototypical homes?
4. Please confirm that the cost estimate includes costs for the design, permitting, and installation phases of the project?
5. Does the cost estimate include profit and material markup? If so, what percentage(s) of each are included?

Additionally, can you please answer the following two general questions that are listed on the sheet for the Colonial home:

1. Approximately how many home fire sprinkler installations has your firm performed in MA between 2021 and 2022?
2. Approximately what percentage your firm's workload between 2021 and 2022 were comprised of home fire sprinkler projects?

Please fill out the grid, on the next page, with your answers. Once completed, please email the grids back to me at felix.zemel@tufts.edu.

PLEASE NOTE: In order to protect your firm's privacy, all responses will be regarded as confidential and will be stored in accordance with Tufts University policy to protect your firm's privacy. This confidentiality includes not listing the name(s) of any firms who respond to this survey.

Thank you very much for your help with this work.

Felix I. Zemel, MCP, MPH, CBO, RS, DAAS
DrPH Candidate, Tufts University School of Medicine

HOUSE TYPE: Colonial					
CITY	**SYSTEM TYPE**	**BACKFLOW PREVENTER**	**TOTAL COST (USD)**	**PHASES INCLUDED**	**PROFIT / MARKUP**
Lowell	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Boston	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Worcester	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Springfield	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______

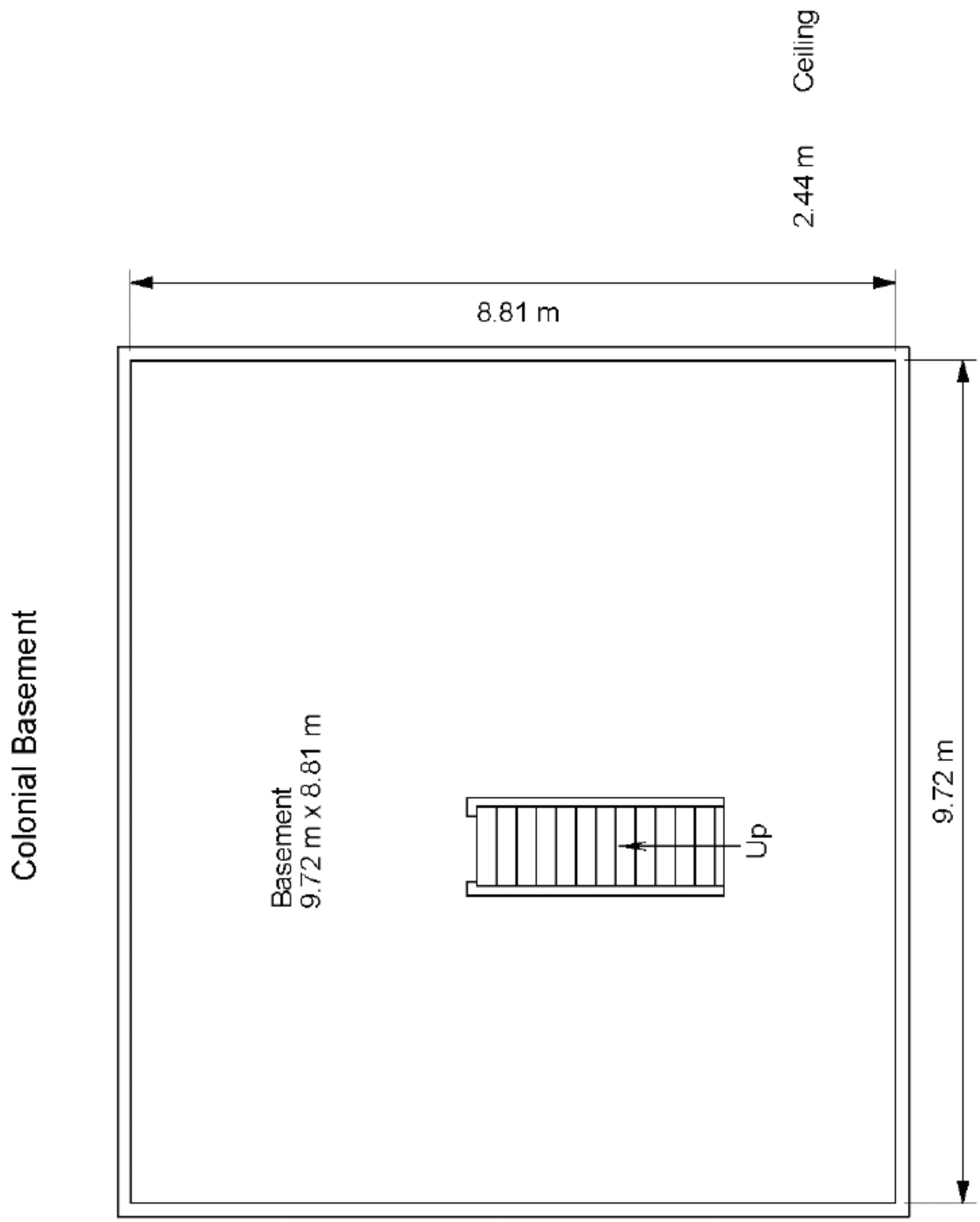
Approx. number of new home fire sprinkler installations performed in MA between 2021 and 2022: ______________________

Approx. percentage of firm's workload is made up of home fire sprinkler projects between 2021 and 2022: _________________

HOUSE TYPE: Townhouse					
CITY	**SYSTEM TYPE**	**BACKFLOW PREVENTER**	**TOTAL COST (USD)**	**PHASES INCLUDED**	**PROFIT / MARKUP**
Lowell	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Boston	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Worcester	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Springfield	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______

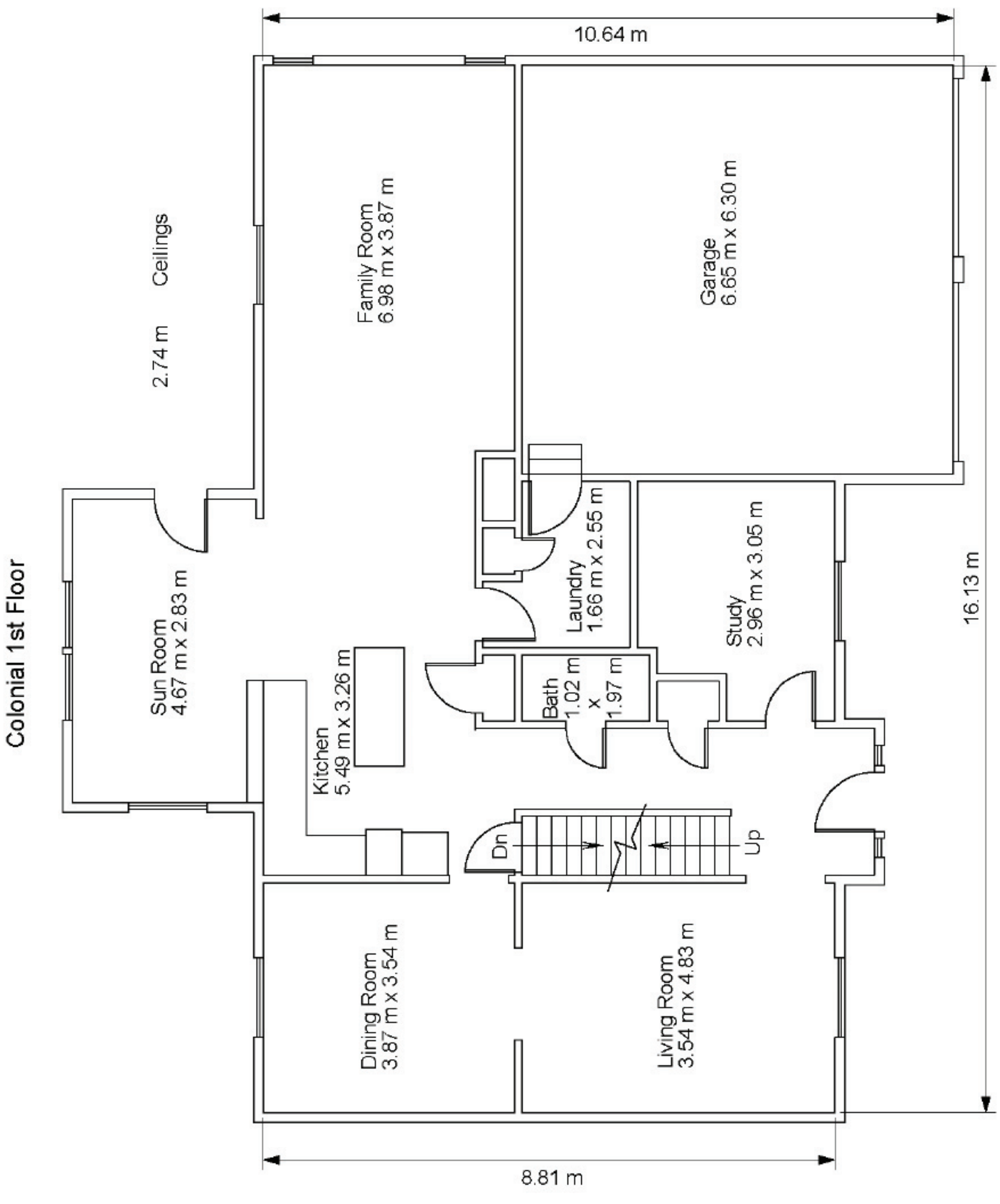
HOUSE TYPE: Ranch					
CITY	**SYSTEM TYPE**	**BACKFLOW PREVENTER**	**TOTAL COST (USD)**	**PHASES INCLUDED**	**PROFIT / MARKUP**
Lowell	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Boston	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Worcester	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______
Springfield	☐ Standalone ☐ Interconnected / Networked (e.g., Uponor) ☐ Other: _______	☐ Yes ☐ No	$ _________	☐ Design ☐ Permitting ☐ Installation	☐ Profit included. If so, percent: ________ ☐ Material markup included. If so, percent: _______

Figure A-1. Prototypical Colonial House: Basement Floorplan



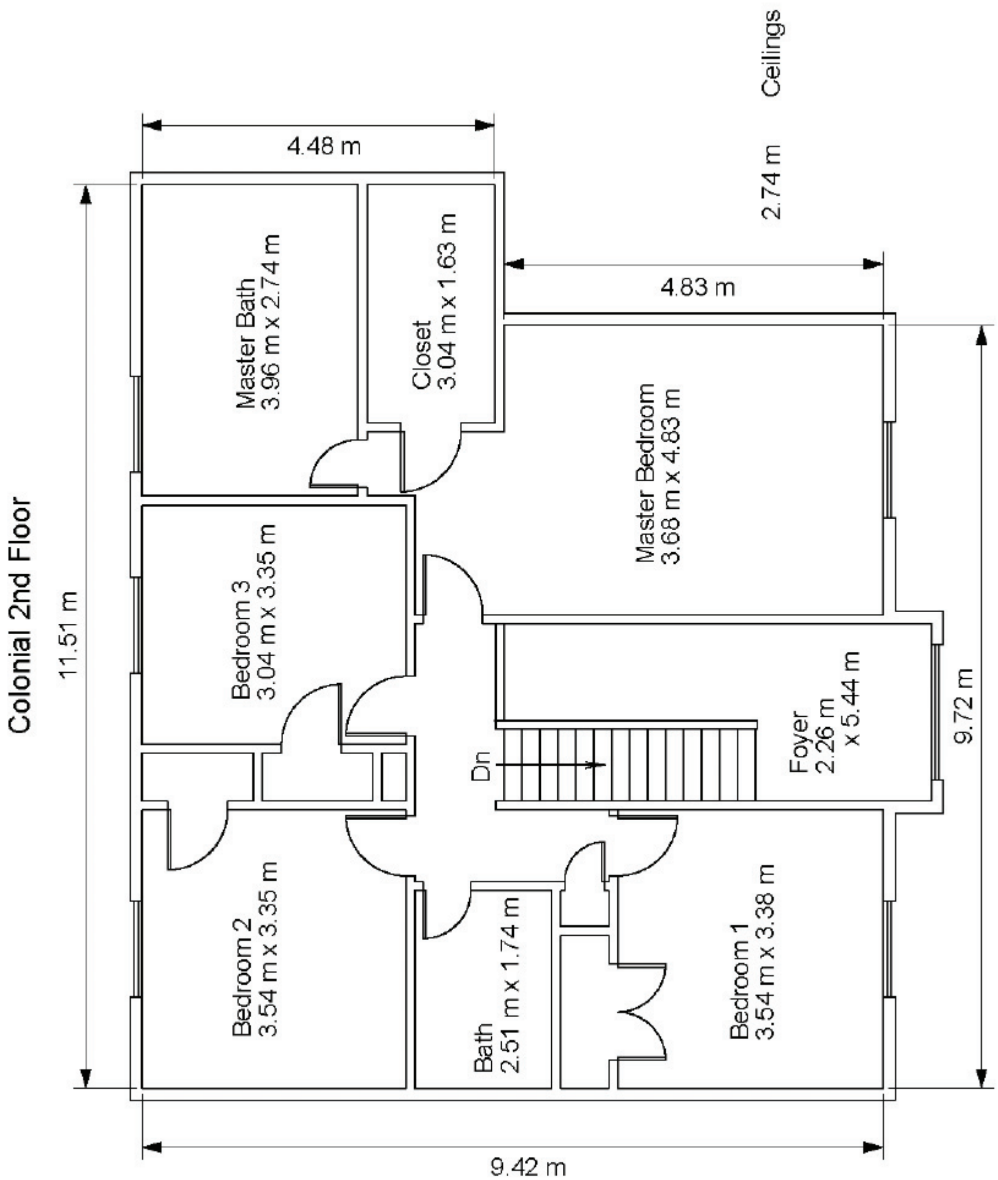
SOURCE: Brown (2005)

Figure A-2. Prototypical Colonial House: 1st Floor Floorplan



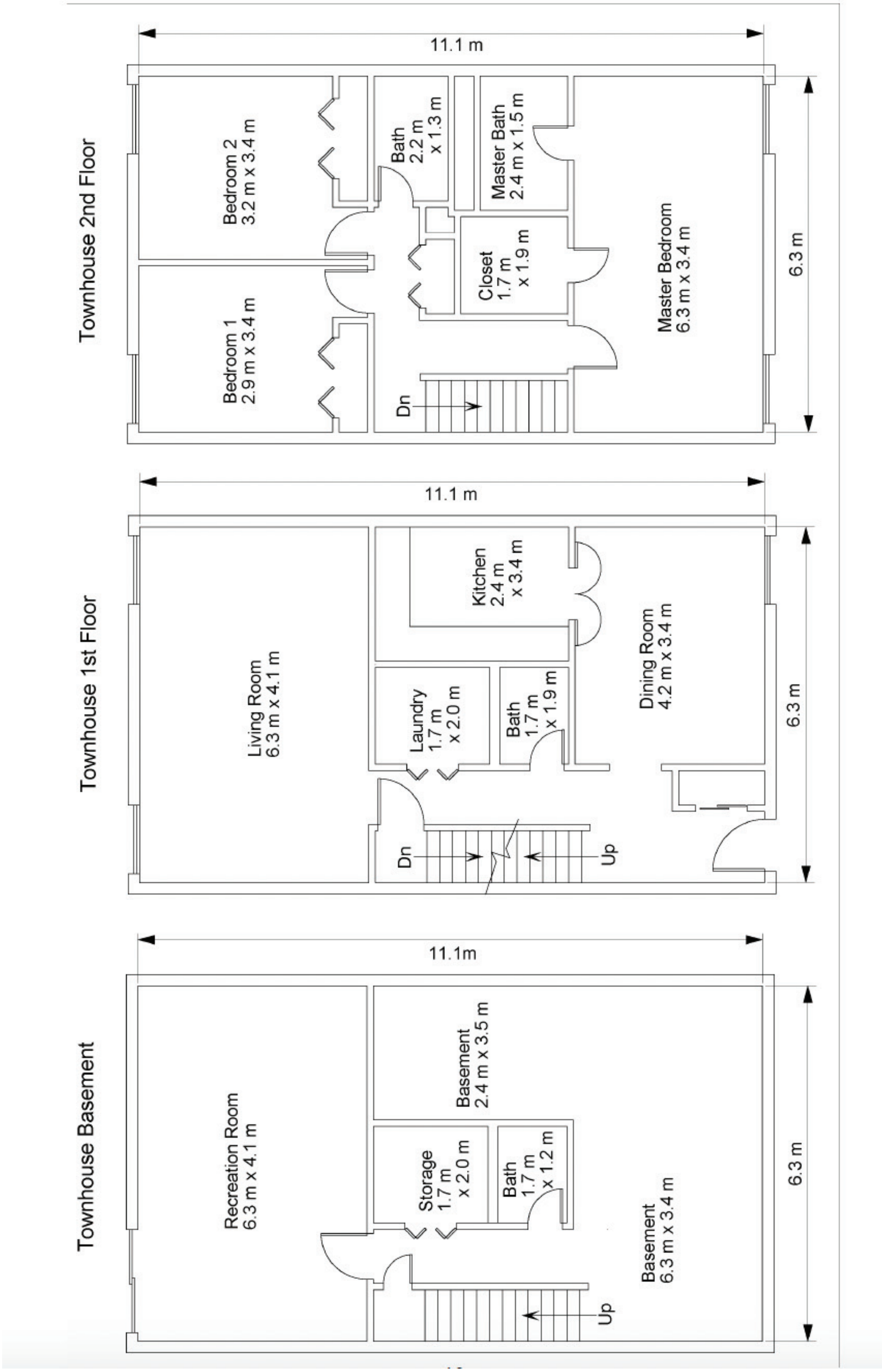
SOURCE: Brown (2005)

Figure A-3. Prototypical Colonial House: 2nd Floor Floorplan



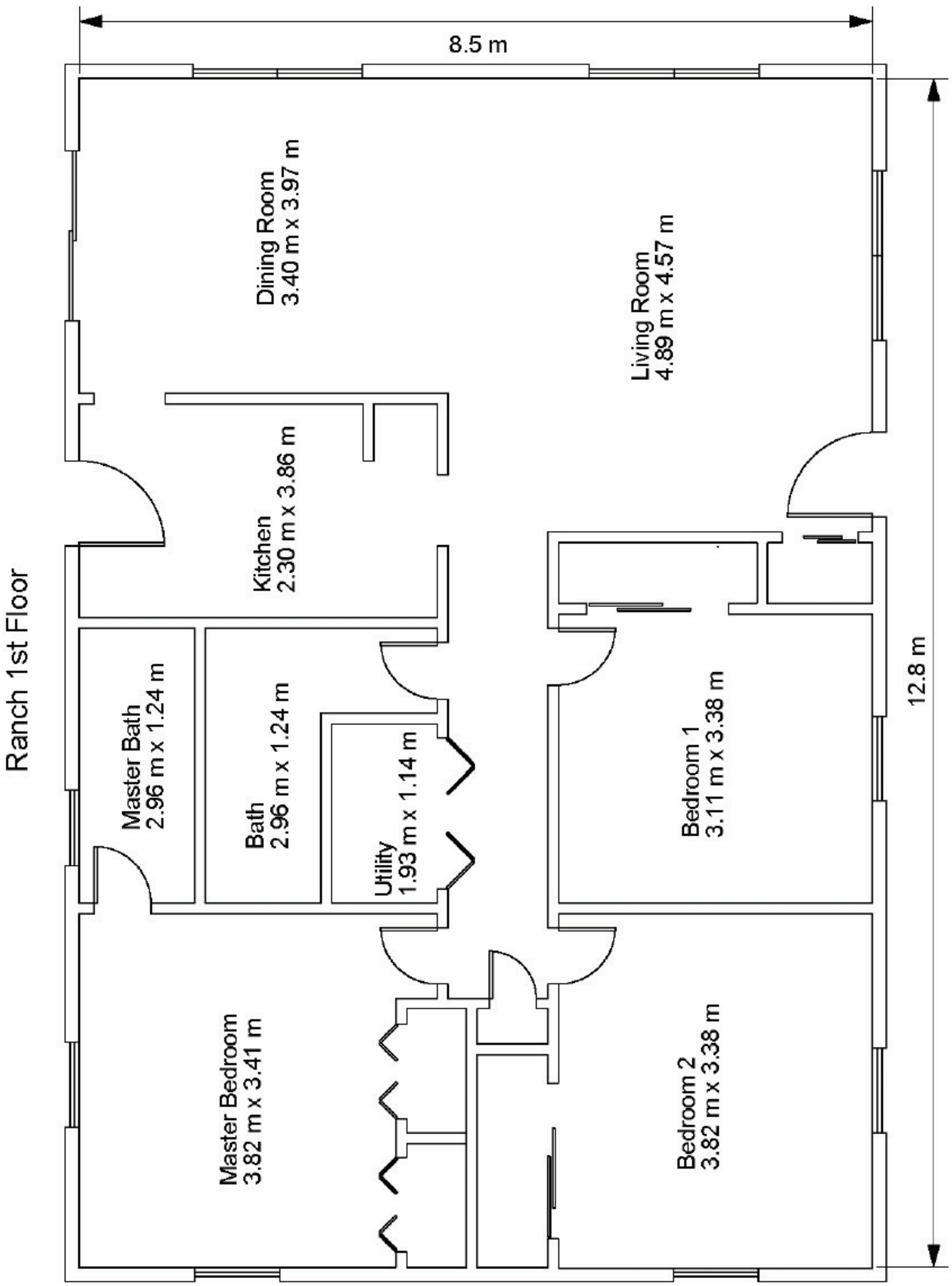
SOURCE: Brown (2005)

Figure A-4. Prototypical Townhouse Floorplans



SOURCE: Brown (2005)

Figure A-5. Prototypical Ranch Floorplan



SOURCE: Brown (2005)

Appendix B: House Bill 2289 -- An act relative to enhanced fire protection in new one- and two-family dwellings

HOUSE DOCKET, NO. 1257   FILED ON: 1/18/2023

HOUSE . . . . No. 2289

The Commonwealth of Massachusetts

PRESENTED BY:

Ruth B. Balser and Paul J. Donato

To the Honorable Senate and House of Representatives of the Commonwealth of Massachusetts in General Court assembled:

The undersigned legislators and/or citizens respectfully petition for the adoption of the accompanying bill:

An Act relative to enhanced fire protection in new one- and two-family dwellings.

PETITION OF:

NAME:	DISTRICT/ADDRESS:	DATE ADDED:
Ruth B. Balser	*12th Middlesex*	*1/18/2023*
Paul J. Donato	*35th Middlesex*	*1/18/2023*
Michael O. Moore	*Second Worcester*	*1/18/2023*
Tram T. Nguyen	*18th Essex*	*1/24/2023*
Jessica Ann Giannino	*16th Suffolk*	*1/24/2023*
Brian W. Murray	*10th Worcester*	*1/25/2023*
Margaret R. Scarsdale	*1st Middlesex*	*1/27/2023*
Adrianne Pusateri Ramos	*14th Essex*	*1/27/2023*
David M. Rogers	*24th Middlesex*	*1/27/2023*
Patricia A. Haddad	*5th Bristol*	*1/30/2023*
Christopher M. Markey	*9th Bristol*	*2/2/2023*
Jeffrey Rosario Turco	*19th Suffolk*	*2/13/2023*
Simon Cataldo	*14th Middlesex*	*2/14/2023*
James B. Eldridge	*Middlesex and Worcester*	*2/17/2023*
Kate Lipper-Garabedian	*32nd Middlesex*	*2/23/2023*
Jonathan D. Zlotnik	*2nd Worcester*	*3/2/2023*
Adam Scanlon	*14th Bristol*	*3/29/2023*
Joan B. Lovely	*Second Essex*	*5/23/2023*

1 of 1

HOUSE DOCKET, NO. 1257 FILED ON: 1/18/2023

HOUSE . . . . No. 2289

By Representatives Balser of Newton and Donato of Medford, a petition (accompanied by bill, House, No. 2289) of Ruth B. Balser, Paul J. Donato and others relative to the installation of automatic sprinkler systems in certain new family dwellings. Public Safety and Homeland Security.

[SIMILAR MATTER FILED IN PREVIOUS SESSION
SEE HOUSE, NO. *2417* OF 2021-2022.]

The Commonwealth of Massachusetts

In the One Hundred and Ninety-Third General Court
(2023-2024)

An Act relative to enhanced fire protection in new one- and two-family dwellings.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows:

SECTION 1. Chapter 148 of the General laws, as appearing in the 2012 "Official Edition", is hereby amended by adding the following new section: -

Section 26J. In any city or town which accepts the provisions of this section, every newly constructed building, designed or used for residential occupancy and containing not more than two dwelling units, shall be protected throughout with an adequate system of automatic sprinklers installed in accordance with the provisions of the state building code. The provisions of this section shall apply to any such newly constructed building for which a building permit is issued on or after one year from the acceptance of this act by a city or town. Nothing in this section shall require any existing building designed or used for residential occupancy, to be required to retrofit said property with an automatic sprinkler system.

The head of the fire department shall enforce the provisions of this section.

Whoever is aggrieved by the head of the fire department's interpretation, order, requirement, direction or failure to act under the provisions of this section, may, within forty-five days after the service of notice thereof, appeal from such interpretation, order, requirement, direction, or failure to act, to the board of appeals as provided in section 201 of chapter six.

SECTION 2. Section 27A of chapter 148, as so appearing, is amended by inserting, after the word "service", in lines 17 and 18, the following new sentence: - This section shall not apply to the seasonal shut-off of automatic sprinklers installed in accordance with the provisions of section 26J of chapter 148, when such shut off has been conducted in accordance with the procedures established by the Board of Fire Prevention Regulations. For purposes of this section, the Board shall determine what constitutes a seasonal shutoff of automatic sprinklers.

Appendix C: Senate Bill 1552 – An act relative to enhanced fire protection in one- and two-family dwellings

SENATE DOCKET, NO. 892 FILED ON: 1/18/2023

SENATE . . . . No. 1552

The Commonwealth of Massachusetts

PRESENTED BY:

Michael O. Moore

To the Honorable Senate and House of Representatives of the Commonwealth of Massachusetts in General Court assembled:

The undersigned legislators and/or citizens respectfully petition for the adoption of the accompanying bill:

An Act relative to enhanced fire protection in new one- and two-family dwellings.

PETITION OF:

NAME:	DISTRICT/ADDRESS:	
Michael O. Moore	*Second Worcester*	
Ruth B. Balser	*12th Middlesex*	
Jason M. Lewis	*Fifth Middlesex*	*1/24/2023*
Jessica Ann Giannino	*16th Suffolk*	*1/24/2023*
Brian W. Murray	*10th Worcester*	*1/25/2023*
Susan Williams Gifford	*2nd Plymouth*	*2/8/2023*
John C. Velis	*Hampden and Hampshire*	*2/8/2023*
Sal N. DiDomenico	*Middlesex and Suffolk*	*2/15/2023*
James B. Eldridge	*Middlesex and Worcester*	*2/22/2023*
Lydia Edwards	*Third Suffolk*	*3/2/2023*
Paul R. Feeney	*Bristol and Norfolk*	*4/12/2023*
Joan B. Lovely	*Second Essex*	*5/23/2023*
Joanne M. Comerford	*Hampshire, Franklin and Worcester*	*6/8/2023*

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SENATE DOCKET, NO. 892 FILED ON: 1/18/2023

SENATE . . . . No. 1552

By Mr. Moore, a petition (accompanied by bill, Senate, No. 1552) of Michael O. Moore, Ruth B. Balser, Jason M. Lewis, Jessica Ann Giannino and other members of the General Court for legislation relative to enhance fire protection in new one- and two-family dwellings. Public Safety and Homeland Security.

[SIMILAR MATTER FILED IN PREVIOUS SESSION
SEE SENATE, NO. *1627* OF 2021-2022.]

The Commonwealth of Massachusetts

In the One Hundred and Ninety-Third General Court
(2023-2024)

An Act relative to enhanced fire protection in new one- and two-family dwellings.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows:

SECTION 1. Chapter 148 of the General Laws, as appearing in the 2020 Official Edition, is hereby amended by adding after section 26I, the following section: -

Section 26J. In any city or town which accepts the provisions of this section, every newly constructed building, designed or used for residential occupancy and containing not more than two dwelling units, shall be protected throughout with an adequate system of automatic sprinklers installed in accordance with the provisions of the state building code. The provisions of this section shall apply to any such newly constructed building for which a building permit is issued on or after one year from the acceptance of this act by a city or town. Nothing in this section shall require any existing building designed or used for residential occupancy, to be required to retrofit said property with an automatic sprinkler system.

The head of the fire department shall enforce the provisions of this section.

Whoever is aggrieved by the head of the fire department's interpretation, order, requirement, direction or failure to act under the provisions of this section, may, within forty-five days after the service of notice thereof, appeal from such interpretation, order, requirement, direction, or failure to act, to the board of appeals as provided in section 201 of chapter 6.

SECTION 2. Section 27A of chapter 148, as so appearing, is amended by inserting, after the word "service", in line 19, the following sentence:- This section shall not apply to the seasonal shut-off of automatic sprinklers installed in accordance with the provisions of section 26J of chapter 148, when such shut off has been conducted in accordance with the procedures established by the Board of Fire Prevention Regulations. For purposes of this section, the Board shall determine what constitutes a seasonal shutoff of automatic sprinklers.