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Review

Social and economic characteristics as determinants of residential fire risk in urban neighborhoods: A review of the literature

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ABSTRACT

The article reviews the literature on social, economic, and building stock characteristics as they relate to residential fire risk in urban neighborhoods. The article updates a previous review of the literature, and provides an overview of recent activity and emergent research directions. A multidisciplinary review of the literature includes sociology, geography, urban planning, and interdisciplinary studies. Whereas multiple regression modeling was the most prevalent technique, the adoption of geographic information systems and advancement of theories on fire risk have deepened and expanded the techniques used, particularly in the area of geography and spatial statistics. Despite recent progress, the state of research continues to be underfunded and isolated within disciplines, frustrating broader application of findings to actual preventive activity by governments. The article also offers suggestions for further research.

Contents

1. Scope

This paper will review the literature on residential fire risk, and its relationship to social and economic characteristics. Direct losses from fires account for between .05 and .22 percent of GDP among industrialized nations [1]. Residential fires are a worthy area of inquiry, consistently accounting for roughly 75 percent of fire casualties in the United States [2]. A similar profile of casualties occurs in other nations as well [3]. Although this review is limited to English-language literature and emphasizes the United States, its findings are more widely generalizable across developed urban areas to the degree that underlying social dynamics and the built environment are common across nations. Indeed there is much common work being done across several English-speaking countries. This article is intended to update a previous review of the literature [4].

This review will, of necessity, discuss complementary literature that predates some of the key research in this area. The review will emphasize inquiries from fields of sociology, urban planning, geography, and interdisciplinary studies. The literature will be limited to residential fires, and will deal primarily with intra-city analysis from the perspectives of the neighborhood and household level.

There is a sizable literature from the public health and medical fields dealing with fire risk as it pertains to casualties. However, this literature will not be reviewed. Similarly, this review will not include literature related to protective measures in the built

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environment, or engineering dimensions of building codes or fire behavior. From a public policy perspective, preventive activities will be discussed only as they offer logical outcomes of the fire risk-related research within this review. As such, the engineering literature on fire extinction is not included in this review.

The paper begins with a brief history of research on fire and its effects on communities and individuals, and then reviews the literature from its inception through the present, with a distinction between eras in research and analysis. Theories of fire risk are reviewed, including a review and commentary on the role of race in determining fire risk. The paper closes with a discussion of future research directions and a discussion of policy interventions arising from scholarly research in this area.

2. The impetus for understanding fire in the built environment

Fire in the built environment is a topic of sustained interest to society, and much of the seminal work in this area arose from concerns of the insurance industry and the prevention of urban conflagrations. Great urban fires destroyed parts of many U.S. urban centers in the late nineteenth and early twentieth century. The response to these fires took place mainly in the realms of engineering and public administration, concerned with fire safety techniques in building design and practice, and planning regulation and fire protection services, respectively [5,6]. Despite this long history, research into fire in the community residential context has remained fragmented and isolated by discipline.

Indeed, fire is both a social and physical phenomenon. Fire transcends the individual, and simultaneously affects the built environment, which includes knock-on effects for the economic livelihood of communities and viability of individual buildings and their surrounding neighborhoods as effective locations for healthy and productive human activity, including both societal reproduction and economic sustainment and progress.

In the years following the control of the conflagration problem, steady progress was made in the reduction of fire losses mainly in non-residential properties – such as business and manufacturing occupancies – that were subject to increased regulation from government, insurance, and industry forces. Despite these areas of progress, residential fires continued to exact a significant toll on people who reside in these structures, and gathered additional attention.

2.1. The history of residential fire research

The understanding of residential fires has traditionally received limited and sporadic attention from a diverse set of scholarly disciplines. As a consequence, much work was done in disciplinary isolation, and with little or no follow-up. This section of the paper will review the history of funding for social research into residential fires, and describe the disciplinary and methodological emphasis of these early efforts.

2.1.1. US federal government role

If there is a primary catalyst for stimulating research into residential fires in the United States, it is the publication of *America Burning*, the 1973 report of the National Commission on Fire Prevention and Control [7]. This report, authored by a Presidentially-appointed panel drawn from broad representation of stakeholders in the fire problem, was unusually effective, leading to a reorganization of the then-federal government's approach to the urban fire problem, and publicly recognizing the dearth of knowledge upon which to design interventions to further reduce the fire problem.

However, this report and the Commission were the product of the Fire Research and Safety Act of 1968 (PL 90–259). The passage of this Act was surely influenced by the surge in fires that occurred in the late-1960s associated with racial unrest, urban economic decline, and notable high-profile fires. In his signing statement, for the Act creating the Commission, President Lyndon Johnson cited the high fire loss statistics for the US, antiquated firefighting techniques, and the need to begin a coordinated federal fire research program [8]. The Commission's preliminary report suggested that fires were comparable in cost to crimes, and therefore “warrants the significant attention of the public and governments at all levels” [9].

Institutionally, the National Fire Prevention and Control Administration (NFPCA) was formed within the Department of Commerce following federal legislation in 1974. The Department was home to the federal government's fire laboratory, the then-National Bureau of Standards [10]. Notable achievements of this agency included development of a national system for collecting fire data from local fire departments, and a well-funded interdisciplinary research program was initiated to better understand dimensions of the fire problem. Within a few years, the NFPCA was reorganized into the United States Fire Administration, and around the same time, its funding was cut, drastically reducing social research into the residential fire problem. A similar initiative to fund scholarly fire research was never repeated at the same scale.

2.1.2. Limitations of early research

As a consequence of federal funding appropriated in the brief span between formation of the NFPCA and its subsequent reorganization and budget reductions, much of the founding work in this area was completed over a short time span, and was understandably exploratory in nature [4].

Because much of this research was done concurrently, there was limited opportunity to learn from previous efforts. Additionally, reliable national data were just becoming available in the United States, with the advent of the National Fire Information Reporting System (NFIRS).

Additionally, analytic and computational techniques at this time predated emergence of personal computers and modern geographic information systems, which greatly limited the ease with which data sources could be integrated. Studies examining geographic dimensions of the fire problem, and the relationship between social, economic, and building stock characteristics were labor intensive and costly, often requiring hand mapping.

Many of these early studies were necessarily descriptive in nature. Some studies used statistical correlations between fires and various characteristics of the population and building stock. More ambitious studies utilized multiple regression to explore the connections between these characteristics and various conceptualizations of fire risk. Some studies were purely explanatory and theoretical, while others were informed by prevailing beliefs or hypotheses of the day.

3. Review of seminal research 1970–2000

These early studies identified the distinct finding that fires were not inevitable, nor were they “acts of god” – rather, they could be prevented. Additionally, the incidence or burden of these fires was not uniformly or randomly distributed – there was systematic variation in the nature and severity of the fire problem across urbanized areas. Ecological approaches to studying fire risk were used to develop meaningful hypotheses [11]. These early ecological approaches to fire risk arose in the urban planning literature, often in association with housing conditions and neighborhood population density. Examples of such works include

Gunther [12], Karter and Donner [13], and Munson and Oates [14]. The ecological approach was fruitful because it recognized the complex web of technical, organizational, economic, and human dynamics as they interact against a context of a built environment to produce fire losses [15].

Although findings were inconsistent between studies, relationships between poverty and housing quality were consistently identified as being associated with greater incidence of fires in residential buildings. Neighborhood conditions, including functional or economic obsolescence of housing units could lead to greater risk of fires, arson, and abandonment of properties [16–20].

Wallace and Wallace singlehandedly produced an impressive literature linking fires to broader negative consequences, including general public health. They theorized that social conditions resulting from unchecked fires could undermine confidence in the neighborhood, leading to a self-reinforcing process of decline and heightened fire risk. In particular, overcrowding further strains building infrastructure, heightening the incidence of fires caused by mechanical defects [21,22]. Sternleib also found that these fire-damaged buildings were prone to abandonment [23].

These studies used numerous measurements to capture effects of social structure, household income, housing stock, and general social conditions. Several studies also demonstrated a relationship between family structure (single parent households with minor children) and residential fire rates. The expected associations between poverty, substandard or overcrowded housing, and increased fire incidence were generally established [24–26].

Munson and Oates identified the relationship between income and ability or willingness to invest in protective equipment. They identified the notion of positive income elasticity of demand for investments such as smoke detectors. That is, higher incomes lead to greater likelihood of maintaining safety equipment [14].

A few limited but promising early studies examined the role of psychological beliefs and attitudes of residents of high fire incidence neighborhoods. These findings, by Bertrand and McKenzie conducted in New Orleans, found that residents held negative expectations for the future of their neighborhoods, and had a lack of community cohesion [27]. These findings supported work done in the UK by Chandler et al. at roughly the same time [28].

Several studies have disaggregated fires by cause and found interesting variations across census tracts between high and low-income areas [29,30]. These studies offer the potential for deeper insights into specific causes and may be effective at identifying specific interventions to target fire scenarios.

These early researchers found that the explanatory power of their models, relying principally on multiple regression, was more significant at the census tract level, demonstrating the importance of scale in measuring and explaining variation in fire rates [13].

The early research efforts conclusively established that fire incidence varies systematically according to social and economic characteristics of residents, and secondarily by housing and neighborhood conditions. Although these factors were operationalized by numerous measures, the early research laid a foundation for consideration of advancing from exploration to explanation.

4. Recent research and analytic tools 2000 to present

A modest resurgence of interest in residential fires and risks associated with socioeconomic and to a lesser degree, building stock characteristics has occurred in the past fifteen years. This research coincided with the availability of geographic information systems (GIS) software which made integration of diverse data tractable for researchers.

Undoubtedly, the greatest progress in residential fire research has been the adoption of GIS as an analytic tool by researchers in this area. A parallel and related development is the improvement of spatial statistics and their improved ease of use through advances in computing power and statistical software. These have permitted large quantities of data to be manipulated, resulting in more complex models and statistical techniques. Geographic information systems (GIS) and more recently, spatial statistics have become the emergent tools for analysis in the field. As a consequence, the subject of residential fire in the urbanized built environment and its relationship to social and economic conditions or characteristics of residents has seen increased scholarly attention in recent years.

Studies of social and economic characteristics and fire risk have continued. These studies are distinguished from previous works by their movement from exploratory studies toward explanation, and a greater emphasis on advancing relationships between fire incidence and other characteristics identified in previous research. These studies have occurred across different settings, and emerged from multiple disciplinary perspectives.

Shai studied fires in Philadelphia using multiple regression analysis to predict fire injuries at the census tract level. Using the injury rate based on population of each tract, she found significant results for variables measuring age of housing, income, and non-English speaking population. There was a significant interaction between low income and older housing. A number of specific fire scenarios were also identified, along with neighborhood effects of vacant housing raising the likelihood of injuries [31].

Asgary et al. examined temporal and spatial dimensions of structural fires in Toronto, Canada. They demonstrated the use of GIS to assist in presentation and analysis of data. Using six classifications of fires – (in decreasing frequency) misuse, electrical and mechanical failures, vandalism, deficiencies in design, construction, or maintenance; arson, and children playing – they produced maps of spatial intensity using kernel density estimation, and also mapped incidents by time of day and month of year. They found that there were clear patterns in both space and time that varied with the types of fires being studied. Additionally, they developed several display methodologies that offered the possibility of replication [32].

Several other studies developed more advanced analytic methodologies by using spatial capabilities of GIS. These studies represent a new level of sophistication and offer possibilities for greater explanation not possible in traditional studies. Because they advance on the methodologies used previously, and are so recent, the individual studies will be addressed here.

Schacterle et al. examined the contribution of vacant buildings to the incidence of fires in Baltimore, Maryland. Since fires in vacant buildings are more likely to spread beyond the structure of origin, they pose an inordinate risk to neighboring properties [33]. Schacterle et al. were able to distinguish between mere presence of vacant dwellings in the census tract and actually measure distance from vacant properties to fire-affected properties. By geocoding both fires and vacant dwellings, they found statistically significant evidence that vacant properties elevated risk of fire for properties within 100 m, and risk was higher the closer a property was to a vacant property. In their study owner occupation of houses was negatively associated with risk [34]. By using GIS and a rich data set, they were able to conclusively demonstrate the association between vacant housing and fire risk. Previously this link was merely association, often at the neighborhood level.

Corcoran et al. have published numerous studies incorporating GIS and spatial statistics in recent years. They have made significant strides, and are developing their own body of research which offers great promise for expanding both understanding and methodological precedents for future work.

Corcoran et al. first examined the adoption of GIS within fire services, and applied this technology to analysis of fire problems.

Using the spatial statistic of kernel density estimation, they used GIS to visualize the density of fires against geographic areas or other proxies of population at risk. By examining fire incidents by type, they were able to associate socioeconomic characteristics with both risk and concentration of specific types of incidents within space [35].

In another study, Corcoran et al. also used co-plots and co-maps to display fire incident data along their *x* and *y* coordinates and also according to a third variable, in their case, time of day. They also used kernel density estimation to overcome artifacts of imposing administrative boundaries on data displays which may obscure patterns. By disaggregating fires by type (location, cause, etc.), and studying their temporal and spatial patterns, they were able to demonstrate the ability of the techniques to assist in interpreting and displaying patterns in data [36].

In a comparative study of Brisbane (AUS) and Cardiff (UK), Corcoran et al. used census socioeconomic characteristics against fires by type to compare the two cities' experiences. They relied on existing census-developed indices of social deprivation and constructed composite variables across both cities' data. These composites included family structure, presence of vehicles in the household, property tenure, ethnicity, education level, and housing type. Using principal components analysis, both cities' data were evaluated and differing composite measures were significant across the types of fires examined, which were building fires, vehicle fires, secondary (outdoor) fires, and malicious false alarms. They noticed associations between social disadvantage and most incident types, although there were differences between the two cities [37].

Chhetri et al. examined building fires in Southeast Queensland, Australia. Using both regression analysis and ANOVA, they used data on socioeconomic characteristics from the Australian Bureau of Statistics to link socio-economic disadvantage to fire incidence. Their regression model to predict fire rates identified five characteristics associated with elevated fire incidence: unemployment; indigenous population; one parent families with children; and a low proportion of families living in separate (detached) dwellings. Each of the terms was statistically significant, and an overall *R*-squared for the model was .45.

Chhetri et al. used some twenty-two socioeconomic variables in the construction of the index of social deprivation, which was compared across census areas. These areas were first compared across their socioeconomic characteristics. Differences in socio-economic characteristics between the high-incidence and low-incidence groups were found to be statistically significant.

A negative relationship between socioeconomic status and fire incidence was observed. Areas with low socioeconomic status had higher incidence of fires. These areas were classified according to fire incidence, and the patterns were preserved.

They examined both the number of fires and the characteristics of dwellings in these areas [38].

Recent research is advancing on the precedent studies, and demonstrating the value that GIS and spatial statistics can bring to analysis of residential fire data. In particular, these studies have permitted analysis of data using methodologies with finer resolution not possible with multiple regression, which dominated previous research. The use of GIS also provides value in displaying results which can be readily usable by policy makers. GIS also has the capacity to serve as a unifying platform for diverse disciplines to undertake analysis, and potentially integrate diverse paths of research. The stage is set for development of a formal, empirically-justified theory of differential fire incidence.

5. Toward a theory of residential fire incidence

The single most important development over the past decade is the beginnings of a theoretical model for residential fire incidence. To understand development of a theory of fire risk requires attention to the scale and precise specification of risk. For example, risk can be measured at the level of the individual, the household, a building, or at the level of the neighborhood. Similarly, fire risk can be conceptualized in terms of risk to people or property. Further, it can be quantified by dollar loss, injuries, deaths, or the more general casualties (injuries plus deaths).

The dynamic of fire risk may vary depending on the level of analysis. We must be careful not to fall prey to ecological fallacy or cross-level inference as we attempt to move from higher-level statistical data to making conclusions about household or individual behavior or risk [39]. Confusion of race as a proxy for income can occur readily. For example, the US Centers for Disease Control and Prevention report that the incidence of tobacco smoking is higher among the low-income population [40]. The increased likelihood of smoking must place these households at greater risk of experiencing fires. The high cigarette usage and heightened incidence of fire and casualties in low-income households suggests that smoking may play a role and that efforts to reduce tobacco use will also lessen the fire risk of the target population. Without considering these behavioral or environmental differences, race can become a catch-all for other behaviors subject to change.

Jennings made the analytic distinction of differentiating between fire initiation and fire loss. This was an effort to consolidate earlier exploratory research and clarify the meaning of fire risk and recognize the distinct dimensions of fire initiation and fire loss. That is, fire incidence (experiencing a fire); and fire loss, (the resulting damage or loss inclusive of damage to the property, and injury to occupants of the dwelling unit or exposed properties). This distinction was part of a conceptual approach that attempted to generalize understanding of residential fires across multiple contexts, and recognize the importance of built environment, protective equipment, and practices, including fire suppression services, in determining the loss from fire. This conceptual approach offers some hope for cross-cultural analysis of the residential fire problem. The approach also explicitly distinguished between fires caused by intentional human acts and those arising from neglectful or negligent behavior and non-proximate human action, such as electrical faults [41].

The model used by Jennings was tested using four years of residential structure fire data drawn from Memphis, Tennessee (USA), a community with a high rate of fire incidence and fire loss compared to national statistics. Jennings developed a four-variable model to explain variation in fire incidence (expressed as fires/capita) across census tracts in Memphis. These four variables were selected based on review of literature and consistent with the conceptual model. The variables used were (1) percent vacant housing units; (2) percent of population under 16 or over 65; (3) household income; and (4) percent of households with children headed by a single parent. The model utilized a weighted least squares regression, and accounted for 83 percent of variation in fire rates between tracts [41]. This represented an improvement both in terms of explanatory power and theoretical consistency over previous models using multiple regression.

Corcoran et al. later expanded on traditional conceptions of fire risk modeling to consider weather and calendar events in addition to socio-economic patterns. Corcoran, Higgs, Rohde, and Chhetri studied five different fire types in Australia, including residential fires. Using Socio-Economic Index for Areas (SEIFA), an index of various income, family and household characteristics, they matched each incident with SEIFA characteristics for that particular geographic area. Calendar events included public holidays, school holidays, and major sports events. Finally, weather was measured using temperature, rainfall and humidity [42].

Corcoran et al. used spatial statistics to develop a “surface” (continuous data of points in a plane) along each of the variables

they used in their model. The data were formed into two groups – one for buildings experiencing fires, and the other a random selection of buildings that did not experience fires in the same time periods. The methodological limitations of traditional 2-sample parametric null-hypothesis methods of analysis are discussed, and alternate approaches utilizing advanced statistical methods and plotting for visual representation of the data are presented. The study found that residential structure fires were more common during winter. Smaller increases were noted during school holidays and long weekends, but decreased slightly during public holidays. Low SEIFA scores were associated with increased risk of residential fires as well. Rainfall did not show an association with incidence of residential fires, but high humidity (atmospheric) was negatively associated with residential fires [43].

Corcoran et al. conclude that "conceptualization of fire incidence requires the adoption of a multidimensional framework that is capable of dealing with phenomena within a multi-scaled context." They then advanced a more elaborate conceptual framework of residential fires, which encompassed the physical environment, neighborhood characteristics, dwelling characteristics, weather, calendar events, and behavior (Fig. 1).

This framework includes major components of: Dwelling characteristics (age, structure, equipment, contents, and dwelling materials); physical environment (topography, vegetation cover, and setting); neighborhood characteristics (demography, cultural practices, and socioeconomic status); weather conditions (temperature, wind speed, and precipitation); individual behavior (perception, values and beliefs, cultural background, and socioeconomic status), calendar events, and group behavior (family lifecycle, household size, and household composition). Linkages between the various components are characterized as "major" or "minor." The ignition of fires can result from sources caused by the dwelling (internal) or through behavioral or neighborhood activity or environment (external). The framework also admits the behavioral origin of intentional (hoax) calls for fire services.

With the development of this framework, a comprehensive structure can be given to accommodate and organize empirical research into the various causes of fires (fire initiation) and the implications for fire losses and also adjustment to response policy, which to date have not been fully included in most research. Most importantly, the framework provides a landscape for orienting future residential fire research.

6. Future research needs

While gains have been made in understanding the differential fire incidence associated with numerous socioeconomic variables, the use of building stock and environmental information is very limited. Equally important, the jump from understanding fire initiation to actual realized fire losses, and the complex interaction of people, environment, and protective policies is virtually untested.

A need for mixed methods of research remains. Rich case studies, and descriptive studies of fire loss patterns and resident characteristics remain important to illuminate local dynamics of the fire problem and identify potential variables useful in future quantitative studies. Perhaps the most promising and unrealized need for research is in undertaking holistic studies of neighborhood conditions simultaneously, using sophisticated analytic techniques, and truly engaging multidisciplinary perspectives. Much research remains isolated by discipline, and to a lesser degree, by analytic methods. Notably, public health research remains somewhat isolated, and should connect with social, economic, and planning or geography researchers for mutual benefit.

Another area of inquiry is to undertake population-based studies to better identify characteristics of – or specific individuals within the community who are at heightened risk of fire. The literature on community dynamics of fire incidence by Wallace and Wallace [22] suggest strongly that heightened fire risk is likely to be co-morbid with increased risk of disease and crime. As indicated, the challenge of disentangling the influences of race, behavioral, and other factors on fire risk remains foremost in terms of both understanding fire risk and designing interventions to reduce risk.

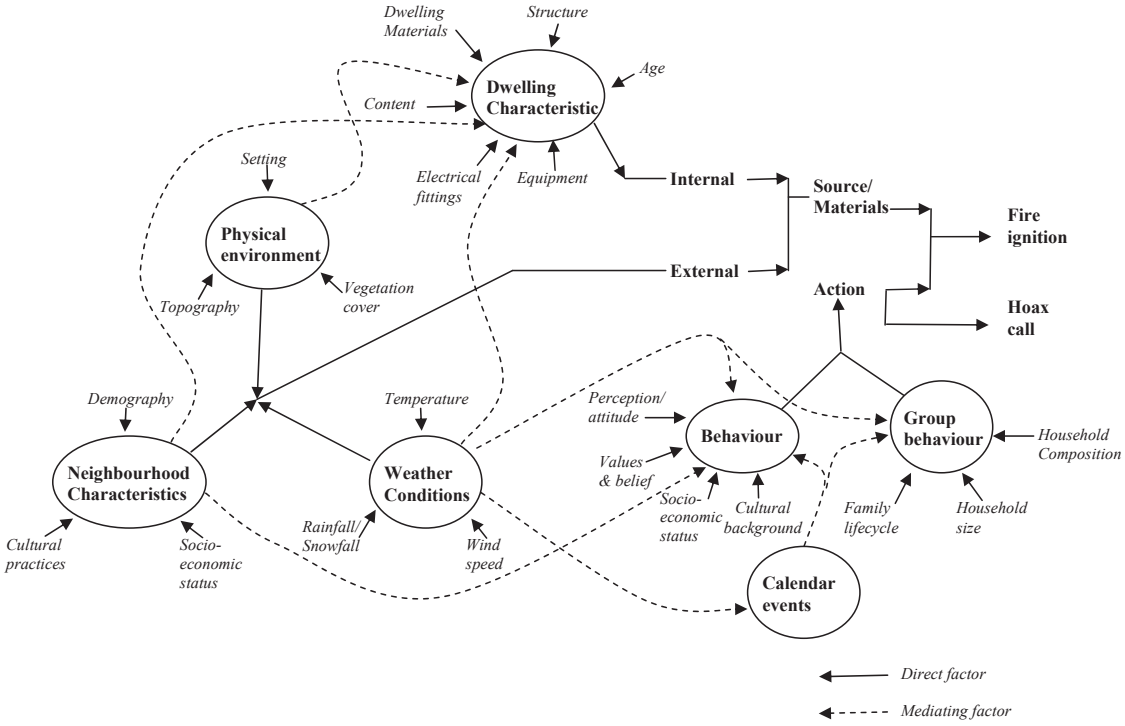

Fig. 1. Conceptual model of fire risk.

Development and pursuit of a coordinated research approach indicates the possibility for comprehensive interventions that address heightened risk from multiple maladies, with equal opportunity for public policy interventions across agencies ranging from public health, fire services, emergency medical services, and law enforcement. Such a program would offer potential to increase the effectiveness of public preventive services which are often delivered in uncoordinated and haphazard fashion, while illuminating conditions that give rise to unhealthy outcomes for neighborhood residents. A side benefit is likely to be more effective and preventive services, with possible benefits outweighing costs in terms of undesired outcomes avoided.

With a credible conceptual model of residential fires, a framework exists to coordinate research and permit greater articulation of results to engender a more holistic understanding of the fire problem. The use of these methodologies could enable linkages to the evaluative studies of fire prevention efforts and to begin to make connections between fire incidence, fire loss, and protective policy.

Funding for research remains meager and effort is diffuse. The situation today, though buoyed by a handful of researchers and partnerships with local fire services, is only modestly improved from 50 years ago, when the US National Research Council decried the state of research into the fire problem [44]. In the US Governmental funding for fire research remains small – despite accounting for significant national-level expenditures for suppression and protective services, not even one percent of expenditures are directed to research. Funding for research today is lower than it was in the early 1980s when the federal government funded many studies [45]. A properly funded research program could improve the efficiency and effectiveness of expenditures for fire suppression services and reduce the number of fires.

Despite this poor picture at the national level in the US, some recent efforts led by local fire services in many countries have embraced the need to improve preventive activities. Prevention is the best way to deal with the fire problem. Despite this truism, comparatively little attention is paid to prevention across many nations. The possibilities of reducing the risk of fire are well-known, but still far from universally applied. Fire safety programs have been demonstrated to be effective at reducing fire incidence, especially when informed by data and involving local fire services [46,47].

In recent years, the United Kingdom, Australia, and New Zealand have systematically realigned protective resources to adopt a more preventive stance. The UK has demonstrated apparent benefits in terms of improved life safety and reduced costs for public protection [48]. Similar efforts in New Zealand have been undertaken by the central government, (http://www.fire.org.nz/Research/Publishsed-Reports/Pages/Publishsed-Reports.aspx).

In nations with a more local tradition of fire protective services, the trend is less hopeful. Recently, however, the United States has undertaken a small research program to encourage local fire services to engage in serious fire prevention efforts, including undertaking quantitative evaluation of outcomes, inspired in part by the efforts of brigades in the UK and New Zealand and funded by a grant from the federal fire authority [49].

Such efforts rely upon the products of academic research, and this valuable component needs to be recognized by governmental authorities. Importantly, these nations' efforts encompass not only studies of fire incidence, but embrace their importance to protective policy in areas such as fire suppression staffing and deployment.

Fire services are best positioned to undertake studies at the level of actual circumstances of households that experience fires. These studies should include identification of specific behaviors and risk factors that directly contribute to fires. These data are crucial to improving our understanding of fire risk and better identifying potential interventions through housing and building codes, public health, education, and behavioral interventions or loss reduction strategies.

Partnership between academics and fire services are essential to better understanding fire incidence and loss, and advancing the record of fire safety and reducing the toll of fire, especially for those communities at greatest risk from fire.

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