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Approaches to residential fire safety – a systematic literature review

Razieh Amiri

Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Norway. E-mail: razieh.amiri@ntnu.no

Petter Grytten Almklov

Department of Sociology and Political Science, Norwegian University of Science and Technology (NTNU), Norway. E-mail: petter.almklov@ntnu.no

Home fires can cause fatalities, severe injuries, and damage to the household assets. Statistics indicate that the current fire safety measures are not effective for all types of dwellers. In many countries, majority of fire fatalities occurs mostly among vulnerable groups. The main objective of this paper is to conduct a systematic literature review in the field of residential fire safety and to evaluate fire safety measures in two perspectives. First, it is investigated which dimensions of fire safety are addressed, such as individual needs, the technical and physical environment, as well as the social and organizational environment. Second, it is investigated whether the studies focused more toward preventing the causes, and/or the consequences. Out of the initial 1303 studies from three search engines, 437 studies were selected for further assessment. The results show that the amount of published research in residential fire safety is generally increasing during the last decades. In recent years only, research has addressed all the three dimensions: individual needs, the technical and physical environment, as well as the social and organizational environment. Considering the total number of articles focusing on preventing the causes and/or consequences, the existing literature seems to be leaning toward measures reducing the consequence of the fire. The studies that aimed to address both causes and consequences, are likely to address more than one of the three dimensions. While research on individual measures and technologies are highly valuable, research that focuses on the interplay of individual needs, the technical and physical environment, as well as the social and organizational environment in residential fire safety can lead to new insights and better prioritization of measures. This can especially be useful in terms of prioritizing and aiding the implementation of measures, thus providing policymakers, governments, and authorities information that can contribute to achieving higher fire safety levels in homes. The need to include the "soft" dimensions of fire prevention is further emphasized by the fact that the majority of residential fires harm specific vulnerable groups. This understanding can be crucial to develop new solutions and measures to find and target the most important ones that can be connected to fire causes and hazardous events, and it can only be achievable through multidisciplinary cooperation with different groups of expertise including health care, social science and humanities, technical fire safety, relevant authorities, stakeholders, as well as representatives for the risk groups and the vulnerable communities.

Keywords: Residential fire safety, home fire, dwellings, systematic literature review, fire safety measures, dimensions, barriers, influencing factors.

1. Introduction

Even though the number of fire fatalities in dwellings have generally been reduced during the last decades (Steen-Hansen, Storesund, and Sesseng 2021; Usfa 2011), home fires can still lead to fatalities and severe injuries for the household residents and cause damage to their assets (Subramaniam n.d.). Therefore, home fires are still considered as a public socio-economic problem in several countries, and many research projects and studies have attempted to reduce the fire risks, and aim to increase the fire safety level in homes to be able to benefit the whole society (Karter 2006; Ministry of Justice and Public Security. 2012; Haagsma et al. 2016). Statistics also indicate that the current fire safety measures have not been effective for all types of residents. For example, research indicates that in many countries a majority of fire fatalities happen in a set of vulnerable groups (Cassidy, McConnell, and

Boyce 2021; Jonsson et al. 2016). Analyzing fire fatality in dwellings, it can be useful to distinguish between three different "layers" containing dimensions of vulnerability and protection as shown in Fig. 1. The individual needs are in the center of the figure. However, it is also affected by the technical and physical environment along with the social and organizational environment (Storesund et al. 2007). To develop and improve new fire safety measures and technologies, the "toolbox" should consider all these dimensions, and how they are connected. The interplay of these three categories of factors can be the initial step for developing new and improving the existing fire preventive measures and technologies. It can also lead to new insights and better prioritization of measures, as well as aid in implementation (Gjøsund et al. 2016). This is only achievable through multidisciplinary cooperation with different groups of expertise including health care, social science and humanities, technical fire safety, relevant authorities, stakeholders, as well as representatives for the risk groups and the vulnerable communities.

Fig. 1.Dimensions affecting the risk of fire fatalities in the home and their relations. Adopted from (Storesund et al. 2007)

The bow-tie model, as shown in Fig. 2, is closely related to the interdisciplinary collaboration. Generally, the bow-tie model introduces two kinds of barriers, I) preventive barriers and II) consequence barriers which are barriers that can minimize the consequences if an accident occurs (Rausand and Utne 2009). A bowtie model can help to identify and map potential fire safety risks, measures and enable professionals from different disciplines to communicate these risks and measures efficiently (Rausand and Haugen 2020). Using the bowtie model and the three different dimensions of vulnerability and protection this article attempts to review the existing studies. It is carried out through a systematic literature review in the field of residential fire safety. This provides an overview of different approaches to residential fire safety.

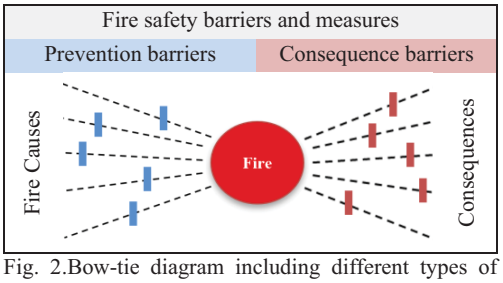

Fig. 2.Bow-tie diagram including different types of barriers. Adopted from (Ministry of Justice and Public Security. 2012)

2. Methodology

The main objective of this paper is to conduct a systematic literature review in the field of residential fire safety, to evaluate the studied fire safety measures from two perspectives. First, in which fire safety risk dimensions are addressed in different aspects including individual needs, the technical and physical environment, as well as the social and organizational environment. Second, it is investigated whether the studies focused more toward preventing the causes, and/or the consequences. The research questions are defined as below.

- How has the development of fire safety measures been addressing the fire safety risk dimensions?
- Have the studies focused more toward preventing the causes, and/or the consequences?

This study has developed based on the 9-stage systematic literature study procedure by (Gough 2007), and to some extent the guideline by Kitchenham (Kitchenham 2007; Kitchenham et al. 2009). In order to cover all the possible articles, three databases were selected for performing this literature study, including Web of

Science (WoS), Scopus, and Engineering Village (EV) platform under Compendex. The similar search string, as below, was conducted on these databases on *7th September 2022* in Trondheim, Norway. (The search results have not been updated after this date.)

("residential fire" OR "home fire*" OR "house fire*" OR "dwelling fire*" OR "fire fatalities" OR "fatal fire*") AND (factor* OR risk* OR assessment OR safety OR indicate* OR protect* OR prevent* OR "smoke alarm" OR sprinkler*)*

2.1.Inclusion and exclusion criteria

The search string aimed to review the title, keywords, and the abstracts of all the articles. The search criteria is limited to the scholarly literature, peer-reviewed literature and journal articles. The language of the search was limited to English only.

2.2.Quality assessment

Through the screening process, the articles that did not address the research questions, were identified as beyond the concept of this article, and they were excluded from the assessment in this literature study. This quality assessment was done by reviewing the main title, subtitle, the keywords, and the abstract for each article. The three-step screening process used is explained below.

Step 1. Exclusion of non-residential fires: These articles included the fire in hotels, hospitals, historical/heritage buildings, restaurants, jails, occupational fires and so on.

Step 2. Exclusion of the identical articles from different search engines: Duplications were identified as same topic, same author, and the same publication year.

Step 3. In-depth screening: The articles that were beyond the concept of this study, were excluded through four filters, explained below.

- Exclusion of residential fires due to natural and environmental hazards, including volcano, hurricane, storm, drought, wildfire, bushfire, forest fire, peat fire, lightning, crown fire, landslide, earthquake, tsunami, flood, and other natural and environmental hazards.
- Exclusion of residential fires due to the industrial activities e.g., wind turbine, process industry, power stations, nuclear and radioactive materials, welding, railroads, aircraft, mines and underground activities, bridge, tunnels other industrial activities.
- Exclusion of residential fires due to other fire hazards, including fireworks, arson, war, terrorist attacks, weapons, and firearms.
- Exclusion of residential fires addressing hazards toward the firefighters at the scenes

2.3.Data collection and data analysis

After conducting the quality assessment, the list of articles was ready for the further data analysis. In this step, the data was collected toward answering the research questions, by reviewing the main title, subtitle, the keywords, and the abstract.

Regarding the 1st research question, the addressed dimensions were identified and categorized based on Fig. 1 for each article. Individual needs, technical and physical environment, as well as the social and organizational environment were respectively marked with "I", "T", and "O". The combination of these marks can also be found e.g., "IO", "IT", "TO" and "IOT". These terms can indicate that there were two or more dimensions discussed in the study. This decision was subjectively made by the first author based on the article review.

Regarding the 2nd research question, each article was analysed whether it was focused more toward preventing the causes, and/or the consequences, respectively marked as "P" and "C". Some articles addressed both preventive and consequence measures in one article. So, these articles were thus marked as "PC".

3. Results

General results for this literature review are shown in Table 1 indicating total 1303 articles in initial identification from the three databases, WoS, Scopus and EV.

Table 1. Number of identified articles and after the three-step screening and quality assessment

	WoS	Scopus	EV	Total
Identification	466	667	170	1303
Step 1.	357	502	142	1001
Step 2.	88	501	39	628
Step 3.	61	347	29	437

After completion of the three-step quality assessment, a total of 437 articles were identified for the further assessment. The main title, subtitle, keywords, and the abstract for each article were then reviewed and the addressed dimension was identified and marked as individual needs (I), technical and physical environment (T), as well as the social and organizational environment (O) and their combinations (IO, IT, TO, ITO). Table 2 shows examples of the data analysis results. The table also includes the markings for 2nd research question that will be presented in the following. The total result based on the addressed dimensions and the publication years is shown in Fig. 3. Note that there is a marked area (1900, 1957 and 1960) in the figure that does not follow the same yearly sequence as the rest of the figure (1975-2022). Results from this figure shows that the amount of research and studies in residential fire safety is generally increasing during the last decades, and only in the recent years, they have addressed all the three dimensions (ITO): individual needs, the technical and physical environment, as well as the social and organizational environment.

Table 2. Examples of data analysis results

Article name and author	Dimension	Barrier	Type of measure
An exploration of causal factors in unintentional dwelling fires (Taylor et al. 2012)	I	P	Preventive individual & behavioural constructs
Sustainability of an in-home fire prevention intervention (Duchossois et al. 2009)	O	P	(Prevention-oriented) information, guidance & policies
Low power wireless smoke alarm system in home fires (Luis, Galán, and Espigado 2015)	T	C	Alarms & detection systems
Transforming fire prevention: A case study (Higgins et al. 2015)	IO	P	(Prevention-oriented) information, guidance & policies
Functional development of residential fire-retardant clothing for older adults (Wang et al. 2021)	IT	C	Home content measures
Are fire safe cigarettes actually fire safe? Evidence from changes in US state laws (Bonander, Jakobsson, and Nilson 2018)	TO	P	Fire safe cigarettes, and Prevention-oriented policies
Fire safety for vulnerable groups: The challenges of cross-sector collaboration in Norwegian municipalities (Halvorsen, Almklov, and Gjøsund 2017)	ITO	PC	(Prevention-oriented) information, guidance & policies

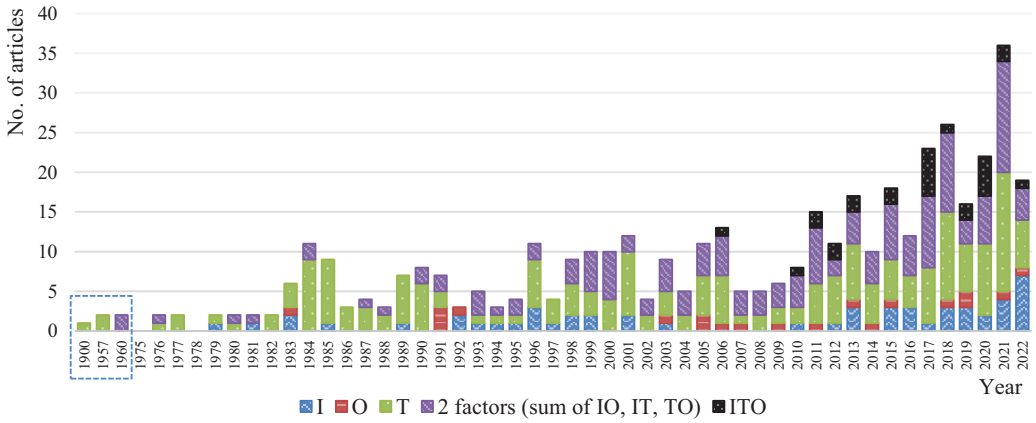

Fig. 3.Number of studies based on the publication year and the addressed dimensions

The number of addressed dimensions in different articles is shown in Table 3. It indicates that the major focus of the studies has been on physical environment, dwelling and technical measures (T:194 studies), combination of individual and technical dimensions (IT:88 studies), and only individual dimensions alone (I:53 studies) in descending order. This data also indicates that the social and organizational dimensions (O:20 studies), and its combinations with other dimensions (IO:26 studies, TO:29 studies, and ITO:27 studies) have not been approached as much as the technical and individual dimensions.

Table 3. Number of articles categorized based on the addressed dimension

Addressed dimension	Number of articles
I	53
O	20
T	194
IO	26
IT	88
TO	29
ITO	27
Total	437

Comparing the total number of articles focusing on preventing the causes and/or consequences, shown in Table 4, the existing literature seems to be leaning toward measures reducing the consequence of the fire (C:176 studies), compared to the measures preventing the fire (P:166 studies). 85 Studies indicates measures both to reduce the fire causes and the consequences (PC:85 studies). In 10 articles, there was not clearly identified any dimensions (N/A:10 studies).

Table 4. Number of articles categorized based on the addressed dimensions and type of barrier

Dimension	P	C	PC	N/A
I	35	13	4	1
O	15	1	4	0
T	48	125	15	6
IO	19	3	3	1
IT	25	26	35	2
TO	15	6	8	0
ITO	9	2	16	0
Total	166	176	85	10

As show in Fig. 4, When taking the physical environment, dwelling and technical measures (T) into consideration, the studies go mostly toward the consequence barriers. However, when the individual dimensions are involved (I), the studies are toward preventive barriers. This figure also indicates that when social and organizational environment are involved (O, IO, TO), the approaches are mostly preventive. The studies that identified to prevent both causes and consequences, are also the most likely to address more than one of the three dimensions (IT, ITO).

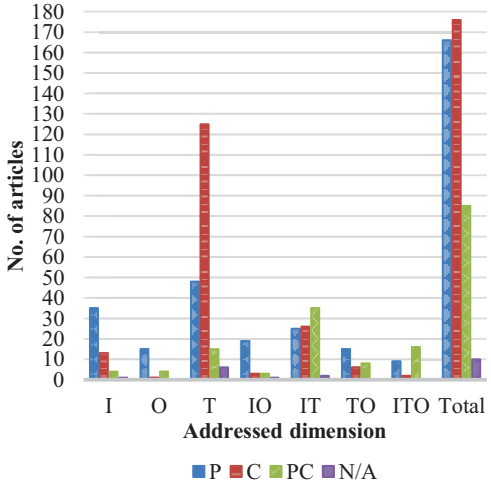

Fig. 4.Bar chart showing the number of articles based on the addressed dimensions and type of barrier

In Fig. 5, an overview of the type of identified preventive and consequence barriers and measures are shown. Home content measures include interior decorations, clothing, upholstered furniture, appliances, home heating and kitchen fire safety measures. On this basis, the majority of the preventive barriers were preventive-oriented information and policies (27%), preventive individual behaviours and constructs (21%) and other types of measures (18%) including mainly sensors, chimneys, volunteer and interdisciplinary organizations. The majority of consequence barriers consists of alarms and detection systems (43%), suppression systems (22%) and home content measures (9%). Other measures mainly consist of information and policies, recovery measures after fire and emergency response volunteers.

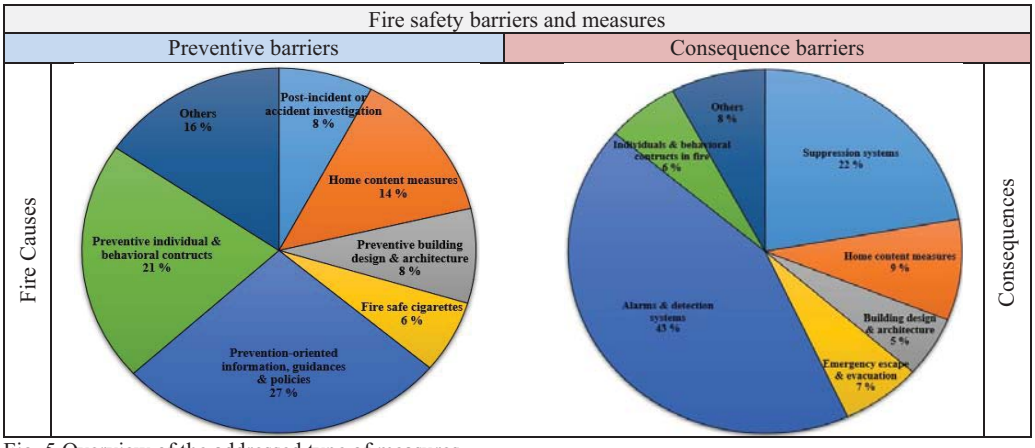

Fig. 5.Overview of the addressed type of measures

4. Discussion and Conclusion

The results from this study show that the amount of research and studies in residential fire safety is generally increasing during the last decades. This might be indicative of an increased interest in the topic but may also reflect the general increasing trend in how much research is published in journals. During the recent years, many studies have addressed all the three dimensions (ITO), including individual needs, the technical and physical environment, as well as the social and organizational environment. It is inferred that the social and organizational, and its combinations with other dimensions have not been approached as much as the technical and individual dimensions.

The existing literature seems to be leaning toward measures reducing the consequence of the fire, compared to the measures preventing the fire causes. However, when the individual dimension is involved, the studies are toward cause and hazard preventions. Also, when social and organizational environment are involved (O, IO, TO), the approaches are mostly preventive. This also indicates the importance of social and organizational environment may have been overlooked in consequence controlling content, and also can be an indication that the technical measures may have been disregarded in the fire preventive measures. On this basis, it can be concluded that further research on practical, efficient and customized development and utilization of preventive technical measures based on the residents' needs can be needed to elevate the fire safety to an acceptable level for everyone. Also, the studies that identified to prevent both causes and consequences, are mostly toward addressing more than one of the three dimensions. These are the more comprehensive and system-oriented studies, and thus more likely to draw in more dimensions than those that focus only on one dimension e.g., only the individual technologies. However, it is indicated in the abstract that these are not necessarily better. Detailed studies of individual barriers and technologies are needed, but the emergence of studies that are more holistic are probably important to help implementation and specially to improve the situation for vulnerable groups.

Research that focuses on the interplay of individual needs, the technical and physical environment, as well as the social and organizational environment in residential fire safety can lead to new insights and better prioritization of measures. This can also be useful in terms of prioritizing and aiding the implementation of measures through a system-oriented approach. Thus, providing policymakers, governments, and authorities advice that can contribute to achieving effective solutions for all types of residents and therefore higher fire safety levels in everyone's home. For a set of vulnerable groups perhaps only "simple" technological solutions is not the best for them. This understanding can be crucial to develop new solutions and measures to find and target the most important ones that can be connected to fire causes and hazardous events. This can only be

achievable through multidisciplinary cooperation and system-oriented approach with different groups of expertise including health care, social science and humanities, technical fire safety, relevant authorities, stakeholders, as well as representatives for the risk groups and the vulnerable communities.

5. Limitations and Recommendations for Further Research

The search process was done on 7th September 2022 in Trondheim. So, the search is not updated after this time and there can be new publications in the later months.

The search process and some analysis has been done manually by the author alone which may bring the possibility for mistake or bias of subjective judgement in the analysis. For the further publication, it can be highly recommended to repeat the analysis multiple times, perform it in group, and/ or to use machine learning to reduce the probability of such limitation.

This literature study was done by reviewing the main title, subtitle, the keywords and the abstract for each article. However, reading the full paper could extract more dimensions. This process can also be facilitated by using machine learning to automize the process.

It is also crucial to include the snowballing process in the literature review process to include more articles from the different countries.

Further study can be done deeper on the subject of interest e.g., the upholstered furniture measures will be studied deeper as it is relevant to the first author work. On the other hands, some of the identified measures in this study may not be relevant for the further study in this study e.g., based on Norwegian fire statistics, children and young adults fire setting are not as common in USA as in Norway. So, this topic may be overlooked for this study at this time.

On the basis of this literature review, another further study is to perform interviews with informants from different groups of expertise to get a more profound overview over the fire safety dimensions and measures in practice.

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