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Fire Severity Outcome Comparison of Apartment Buildings Constructed from Combustible and Non-Combustible Construction Materials

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Abstract. Wood is commonly used in construction, but often perceived as being less safe than structures made from non-combustible materials. With the advancement of wood products and treatment, construction techniques, and protective systems, this may not be the case any longer. Using retrospective data from fire departments across Canada, this study aimed to determine whether the type of construction material (combustible or non-combustible) affected the fire severity outcome of a one to six storey apartment building fire, after accounting for protective systems (smoke alarms and sprinklers). The study found that, after adjusting for the presence of smoke alarms and sprinklers, structures constructed from non-combustible construction materials did not perform better in terms of injuries, requiring extinguishment by fire department, or the fire spreading beyond the room of origin. The presence of working smoke alarms and sprinklers played a central role in reducing the severity outcome of a fire. Smoke alarms and sprinklers both reduced the odds of extinguishment by the fire department and the fire spreading beyond the room of origin. Sprinklers also reduced the injury rate. Overall, this study highlighted the importance of protective systems in reducing fire severity outcomes.

Keywords: Fire safety, Combustible materials, Non-combustible materials, Apartment fires, Wood-frame structures

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1. Introduction

Wood is natural, sustainable and economical, and is one of the most commonly used materials in construction. It is also combustible, which causes structures constructed from wood to be perceived as being less safe than structures made from non-combustible materials, such as steel and concrete. This sentiment can be seen reflected in the British Columbia (BC) Building Code, where before 2009, wood construction could only be used for structures up to four storeys tall [1]. However, fire safety in residential buildings is multi-layered, and advancements in wood products and treatment, such as fire-retardant treatment and use of non-combustible cladding, have made combustible materials more fire-resistant and protective systems, such as smoke alarms and sprinklers, have increased the rate of detecting and extinguishing the fire before ignition of the building material [2–5]. With these advancements, non-combustible constructions may not hold this advantage over wood any longer. In 2009, the BC Building Code relaxed the restrictions by allowing structures up to six storeys to be constructed using wood construction, encapsulated mass timber is now expected to reach up to twelve storeys in 2020 [6]. The six-storey limit was adopted in the National Building Code of Canada in 2015 [7] and extended to twelve storeys in the 2020 National Building Code [8].

Although there have been numerous studies comparing how buildings and construction materials burn, they were either case studies [9], were measured in controlled environments [10–16], or were computer models of fire outcomes under different fire scenarios [17]. The authors were not able to find any studies directly comparing the fire outcomes of buildings made from combustible and non-combustible constructions in real-world situations. One major reason these studies are lacking may be the absence of adequate data for these comparisons. As jurisdictions have gotten better at collecting and sharing this information, including the advent of the National Fire Information Database (NFID) in Canada, more studies can now be conducted using real-world data.

This study aimed to determine whether the type of construction material affected the severity of a fire after accounting for protective systems (smoke alarms and sprinklers). The NFID was used to explore the effects through a pan-Canada lens and the British Columbia Office of the Fire Commissioner (BCOFC) dataset was used to explore these patterns in BC. Fire severity outcome was measured as: (1) number of fatalities, (2) number of injuries, (3) requiring extinguishment by fire department, and (4) spread of the fire. Only residential apartment buildings that were one to six storeys were included in the study so as to restrict the comparison to similar structures, as apartment buildings are usually better equipped with protection systems and may be built from wood or non-combustible construction materials.

2. Material and Methods

The NFID is a database containing fire incidents and victim data reported by the Fire Commissioners and Fire Marshal Office from seven different jurisdictions across Canada–British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), New Brunswick (NB), and the Canadian Armed Forces (CAF)–spanning the years of 2005 to 2015. However, only BC, AB and MN were included in this study because the other jurisdictions did not collect information on type of construction material. The BCOFC provided the same information for BC, spanning the years 2007 to 2019.

Outcome variables of interest were measures of fire severity outcomes: (1) number of fatalities, (2) number of injuries, (3) requiring extinguishment by fire department (yes or no), and (4) spread of the fire (beyond room of origin or not). Outcomes were considered better if the number of fatalities and injuries were fewer, and the proportions of fires requiring extinguishment by fire department and spreading beyond the room of origin were smaller. Independent variables of interest were type of construction material (combustible or non-combustible) and protective systems in place (no protective systems, smoke alarms only, sprinklers only, or both). Height of the building (number of storeys) was included as a covariate to adjust for the size of the building, as that affects the number of people and rooms potentially exposed to the fire. Type of construction material was considered combustible if the structure was made from open wood joist, wood protected by plaster, or heavy timber; it was considered non-combustible if made from exposed steel, protected steel, or concrete. Sprinklers were considered present if complete or partial sprinkler coverage was noted in the fire report and not present if otherwise. Smoke alarms were considered present if they were noted as activated during the fire and not present if otherwise. If both sprinklers and smoke alarms were present, then it was considered that both protective systems were in place, and if neither were present, then no protective systems were in place.

Descriptive statistics, with 95% Wald's confidence intervals, were conducted by type of construction material and protection systems in place. Independent multivariable models were conducted for each outcome of interest in order to determine whether the type of construction material had a significant effect after adjusting for protective systems and building height. A negative binomial regression model was used to determine the association between fatality/injury rate and the independent variables of interest. The independent variables were construction material, protective systems in place, and height of building. Rate ratios, with 95% confidence limits, were calculated.

A logistic regression model was used to determine the association between the odds of the fire being extinguished by the fire department and the variables of interest, which were construction material, protective systems in place, and height of building. Another logistic regression model was used to determine the association between the odds of the fire spreading beyond the room of origin and the independent variables of interest. For the logistic regression models, odds ratios,

with 95% confidence limits, were calculated. All analyses were conducted using SAS software, version 9.4 (Cary, NC, USA).

3. Results

There were 13,897 apartment fires recorded in the NFID dataset between 2005 and 2015 in the provinces of MN, AB, and BC. 9711 of these fires occurred in apartment buildings between one and six storeys in height, with 962 (10%) reported in MN, 3685 (38%) in AB, and 5064 (52%) in BC. 969 (10%) of the 9711 fires occurred in buildings with both working sprinklers and smoke alarms, 700 (7%) in buildings with working sprinklers only, 3669 (38%) in buildings with working smoke alarms only, 3730 (38%) in building without neither working sprinklers nor smoke alarms, and 643 (7%) had unknown or missing data. 7687 (79%) occurred in buildings made from combustible construction materials, 311 (3%) occurred in buildings made from non-combustible materials, and 1713 (18%) had unknown or missing data. These fires resulted in a total of 74 fatalities and 961 injuries, with 4032 (42%) of fires requiring extinguishment by the fire department, and 1950 (20%) of fires spreading beyond the room of origin (Table 1).

There were 6023 apartment fires recorded in the BCOFC dataset between 2007 and 2019 in BC. 4474 of these fires occurred in apartment buildings between one and six storeys in height. 1011 (23%) of the 4474 fires occurred in buildings with

Table 1
Number of Fires, Death Rate, Injury Rate, Proportion of Fires Extinguished by Fire Department, and Proportion of Fires That Spread Beyond Room of Origin by Type of Construction Material and Protection System in BC, AB, and MN, Canada, 2005–2015 (NFID Dataset)

Variable	Label	Fires (N)	Death rate (per 100 fires) [95% CI]	Injury rate (per 100 fires) [95% CI]	Extinguished by Fire Department (%) [95% CI]	Spread beyond Room of Origin (%) [95% CI]
Type of Construction	Combustible	7687	0.8 [0.6, 1.0]	11.1 [10.4, 11.9]	43.6 [42.4, 44.7]	20.0 [19.1, 20.9]
	Non-combustible	311	1.6 [0.2, 3.0]	10.9 [7.5, 14.4]	34.7 [29.4, 40.0]	13.5 [9.7, 17.3]
Protection System	None	3061	0.8 [0.5, 1.2]	12.0 [10.9, 13.2]	47.2 [45.4, 49.0]	29.6 [27.9, 31.2]
	Smoke alarm	3132	1.1 [0.7, 1.5]	12.0 [10.9, 13.2]	47.1 [45.4, 48.9]	15.0 [13.8, 16.3]
	Sprinkler	622	0.5 [0.0, 1.0]	7.2 [5.2, 9.3]	36.2 [32.4, 40.0]	17.5 [14.5, 20.5]
	Both	878	0.6 [0.1, 1.1]	11.5 [9.4, 13.6]	35.2 [32.0, 38.4]	10.9 [8.9, 13.0]

both sprinklers and smoke alarms, 564 (13%) occurred in buildings with working sprinklers only, 1734 (39%) occurred in buildings with working smoke alarms only, and 1165 (26%) occurred in buildings with neither working sprinklers nor smoke alarms. 3539 (79%) occurred in buildings constructed from combustible materials, 270 (6%) occurred in buildings constructed from non-combustible materials, and 665 (15%) had unknown or missing data. These fires resulted in a total of 32 fatalities and 429 injuries, with 1794 (40%) fires requiring extinguishment by the fire department, and 421 (9%) fires spreading beyond the room of origin (Table 2).

The results from the NFID and BCOFC datasets were fairly similar. Looking at raw comparisons between types of construction, NFID showed that buildings made from non-combustible construction materials fared better on the outcomes of requiring extinguishment by fire department and spreading beyond room of origin, and were within the confidence limits for death and injury rates, while BCOFC showed that buildings constructed from non-combustible materials fared better on all fire severity outcomes. For protective systems, NFID showed the proportions of fires that required extinguishment by fire department and those that spread beyond the room of origin were at their lowest when both sprinklers and smoke alarms were present, while BCOFC showed the proportion of fires that spread beyond the room of origin was lowest when both sprinklers and smoke alarms were present. When only sprinklers were present, injury rate was lowest in the NFID, while injury rate and proportion requiring extinguishment by fire

Table 2
Number of Fires, Death Rate, Injury Rate, Proportion of Fires Extinguished by Fire Department, and Proportion of Fires That Spread Beyond Room of Origin by Type of Construction Material and Protection System in BC, Canada, 2007–2019 (BCOFC Dataset)

Variable	Label	Fires (N)	Death rate (per 100 fires) [95% CI]	Injury rate (per 100 fires) [95% CI]	Extinguished by Fire Department (%) [95% CI]	Spread beyond Room of Origin (%) [95% CI]
Type of Construction	Combustible	3539	0.8 [0.5, 1.1]	10.7 [9.7, 11.7]	11.4 [10.4, 12.5]	10.5 [9.5, 11.5]
	Non-combustible	270	0.0 [0.0, 0.0]	5.2 [2.5, 7.8]	5.2 [2.5, 7.8]	4.8 [2.3, 7.4]
Protection System	None	994	0.4 [0.0, 0.8]	12.6 [10.5, 14.6]	13 [10.9, 15.1]	15.3 [13.1, 17.5]
	Smoke alarm	1422	1.1 [0.5, 1.6]	11.3 [9.6, 12.9]	12.3 [10.6, 14.0]	8.9 [7.4, 10.3]
	Sprinkler	500	1.0 [0.1, 1.9]	6.2 [4.1, 8.3]	7.2 [4.9, 9.5]	7.8 [5.4, 10.2]
	Both	893	0.3 [0.0, 0.7]	8.6 [6.8, 10.5]	9.0 [7.1, 10.8]	7.5 [5.8, 9.2]

department were at their lowest in BFOFC. There were too few deaths to adequately compare and for further modeling.

For both datasets, fire severity outcomes between combustible and non-combustible construction patterns were different after adjusting for protective systems. Modeling of injury rate and the variables of interest demonstrated that, after adjusting for protective systems and building height, the type of construction material did not have a significant association (Fig. 1). In terms of the protective systems, sprinklers reduced the rate of injuries by 47% in the NFID data and 42% in the BCOFC data, while having smoke alarms only or having both smoke alarm and sprinklers did not have significant associations in either dataset.

Modeling of the odds of requiring extinguishment by fire department did not show significant association with the type of construction material, after adjusting for protective systems and building height in either dataset (Fig. 2). For the protective systems, having smoke alarms only reduced the odds of requiring extinguishment by fire department by 26% in the NFID data and 24% in the BCOFC data, having sprinklers only reduced odds by 39% in the NFID data and 32% in

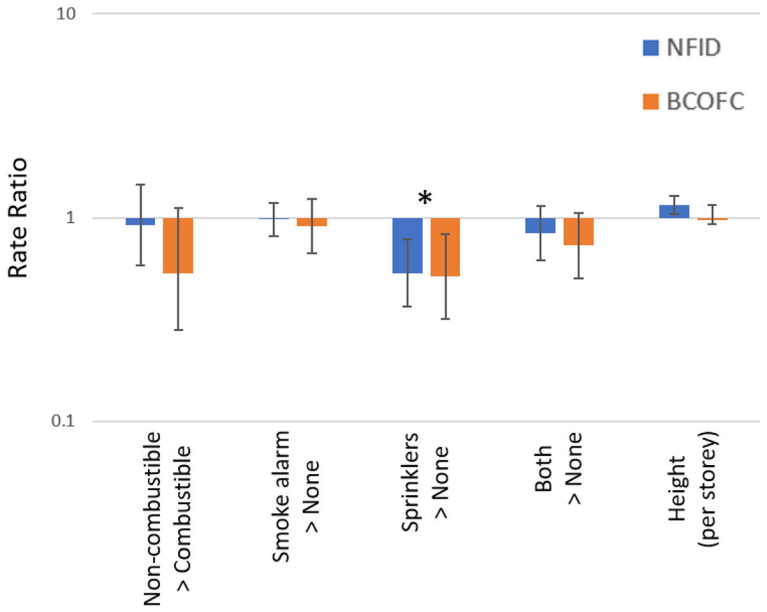

Figure 1. Results from the negative binomial regression model showing rate ratios, with 95% confidence intervals, between the injury rate and variables of interest (construction material, protective systems, building height) for both the NFID and BCOFC datasets. Rate ratios are shown on the y-axis and on a logarithmic scale to better represent its effect size. Contrasts for each variable of interest are shown on the x-axis. Significant associations are marked with an asterisk.

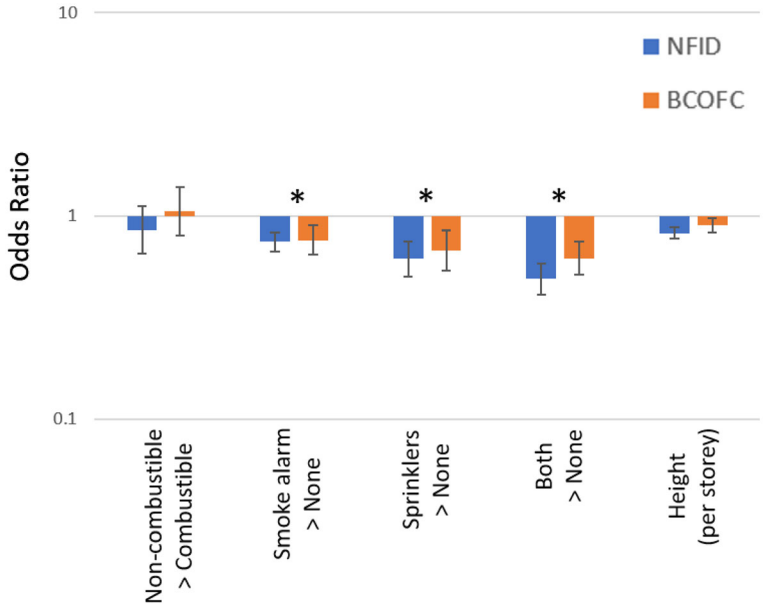

Figure 2. Results from the logistic regression model showing odds ratios, with 95% confidence intervals, between the odds of requiring extinguishment by fire department and variables of interest for both the NFID and BCOFC datasets. Odds ratios are shown on the y-axis and on a logarithmic scale to better represent its effect size. Contrasts for each variable of interest are shown on the x-axis. Significant associations are marked with an asterisk.

the BCOFC data, and having both reduced odds by 51% in the NFID data and 38% in the BCOFC data.

Modeling of the odds of the fire spreading beyond the room of origin did not show significant association with the type of construction material, after adjusting for protective systems and height of the building for either dataset (Fig. 3). For protective systems, having smoke alarms only reduced the odds of the fire spreading beyond the room of origin by 60% in the NFID data and 44% in the BCOFC data, sprinklers only reduced the odds by 50% in the NFID data and 44% in the BCOFC data, and having both reduced the odds by 71% in the NFID data and 45% in the BCOFC data.

4. Discussion

This study included data on 9711 cases of fires in apartment buildings that were one to six storeys tall reported to the NFID in the provinces of BC, MN, and AB spanning the years of 2005 to 2015, and 4474 fires reported to BCOFC in BC spanning the years 2007 to 2019. The results from analysis of the two datasets

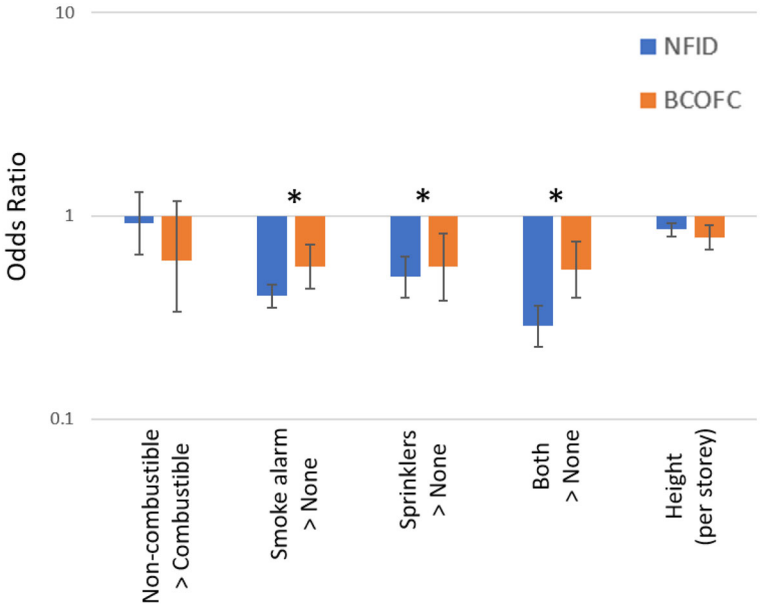

Figure 3. Results from the logistic regression model showing odds ratios, with 95% confidence intervals, between the odds of the fire spreading beyond the room of origin and variables of interest for both the NFID and BCOFC datasets. Odds ratios are shown on the y-axis and on a logarithmic scale to better represent its effect size. Contrasts for each variable of interest are shown on the x-axis. Significant associations are marked with an asterisk.

showed similar patterns, which was not surprising, as BC fires comprised just over half the fires (52%) analyzed in the NFID dataset.

Although raw comparisons suggested that fires in apartment buildings constructed from combustible materials showed worse outcomes than those constructed from non-combustible materials, once the protective systems in place were accounted for, the type of construction material was found not to have a significant association with any of the outcomes of interest. It was the protective systems that had significant associations with our outcomes of interest, which was similar to findings in a 2015 modeling study that found the risk of deaths and injuries due to fire in mid- and high-rise residential buildings were similar between wood and non-combustible construction materials if fire detection and sprinklers were in place [17].

The protective systems were found to have different effects for the different fire severity outcomes. Having working sprinklers reduced injuries, but having smoke alarms in addition to the sprinklers did not. This was likely due to the fact that smoke alarms alert residents to the presence of a fire, thus more residents may attempt to combat the fire, increasing the risk of injuries. For odds of requiring extinguishment by fire department, protective systems had an additive effect, with

sprinklers having a larger protective effect than smoke alarms, but having both systems had the largest protective effect. This may be because smoke alarms alert residents to combat the fire, whereas the role of sprinklers is to suppress the fire, and having both provided two independent layers of fire control. For odds of the fire spreading beyond the room of origin, whether only smoke alarm or sprinkler was present or both, the protective effects were similar. Since sprinklers suppress fires, intuition would suggest sprinklers should have a greater effect than smoke alarms in preventing spread of fires. However, since the presence of sprinkler systems in this study included partial coverage, this may include apartment fires that started in rooms without sprinkler coverage. In these scenarios, sprinklers would only be activated after a fire has spread beyond the room of origin, resulting in a confounding effect on this outcome variable.

It is important to note that due to the multi-layered approach to fire safety, combustible construction materials are only a fire hazard if given enough time and exposure to the fire for ignition. In the event where the fire was detected and extinguished before it had a chance to ignite the construction material, the construction material would not play a role in the outcome of the fire, which may be why the study found that construction materials did not have signification associations with any of the fire severity outcomes measured after adjusting for protective systems. This is a limitation to the study, as fully-developed fires in residential buildings are rare occurrences.

Another limitation is that the study only looked at incidents that required a response by the fire department, thus fire risk could not be measured as data for the number of at-risk buildings for those constructed from combustible or non-combustible materials were not available. In addition, the low counts of deaths, injuries, and number of non-combustible material constructions resulted in larger confidence intervals, which may lead to false negatives. Other limitations in this study include the administrative nature of the datasets, such as missing data and discrepancies in the exact definitions of variables.

5. Conclusions

This study is one of the first studies to look at the effect of the type of construction material on the outcome of fires in the real-world environment. Across the Canadian provinces of BC, AB, and MN, the study found that, safety systems, in the form of smoke alarms and sprinklers, played a much greater role in reducing the severity of a fire than the type of construction material used. Smoke alarms and sprinklers both reduced the odds of extinguishment by the fire department and the fire spreading beyond the room of origin. Sprinklers also reduced the injury rate as a result of an apartment building fire. Taken together, this study highlighted the importance of safety systems in reducing the severity of a fire and supports the notion that all residential apartment buildings should have smoke alarms and sprinklers installed, confirm that coverage is sufficient, and ensure that they are well-maintained. Given the economic and environmental benefits of wood

construction, this study supports the continued use of wood for taller structures, given protective systems and other fire safety practices are in place.

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