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

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Executive Summary

Wood is a natural, sustainable, and economical material used for construction. It is also combustible, which causes structures constructed from wood to be perceived as less safe than structures made from non-combustible materials, such as steel and concrete. 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. In addition, protective systems, such as smoke alarms and sprinklers, have increased the rate of detecting and extinguishing the fire before ignition of the building material. With these advancements, non-combustible constructions may not hold this advantage over wood any longer.

Studies comparing combustible and non-combustible materials in real-word environments are severely lacking and this study was developed to contribute to the field. Using retrospective data from fire incidents from fire departments, this study aimed to determine whether construction material (combustible or non-combustible) affected the severity outcome of a fire, after accounting for protective systems (smoke alarms and sprinklers). 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 to restrict the comparison to similar structures. Data from the National Fire Information Database (spanning 2005 to 2015) was used to explore these effects through a pan-Canada lens, while data from the British Columbia Office of Fire Commissioners (spanning 2007 to 2019) was used to explore these patterns in British Columbia. However, due to missing or insufficient data, only the provinces of British Columbia, Alberta, and Manitoba were included in the pan-Canadian analysis.

The results for both the pan-Canadian and British Columbia focused analyses were similar. There were very few deaths observed as a result of apartment building fires in the study period, resulting in insufficient counts for statistical comparisons. The study found that, after adjusting for the presence of smoke alarms and sprinklers, structures constructed from non-combustible 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 much greater 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 as a result of an apartment fire.

Overall, this study highlighted the importance of safety systems in reducing the severity outcome of a fire and supports the notion that all apartment buildings should have smoke alarms and sprinklers installed, confirm coverage is sufficient, and ensure they are well-maintained. Given the economic and environmental benefits of wood construction, this study also supports the continued use of wood for taller structures. In the form of its limitations, this study also calls to attention the importance of quality and comprehensive data collection in the field, as multiple provinces and a significant number of fire events were excluded due to insufficient or missing data.

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 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, as 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. In addition, 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 reports and studies on comparing how materials burn, the vast majority were measured in controlled environments, were case studies, or computer simulations[9-16]. Studies comparing the performance of these structures in real-word situations have been severely lacking. One major reason for this was the absence of adequate data for these comparisons, but this is no longer the case, as jurisdictions have gotten better at collecting this information, including the advent of the National Fire Information Database (NFID). The NFID houses information associated with structure properties, fire outcomes, and victim characteristics for fires attended to by fire departments across Canada. Many jurisdictions contributed to this database, including the British Columbia Office of Fire Commissioners (BCOFC), which provided the information related to fires in BC. Analyzing these datasets to evaluate and compare the performance of structures made of different materials is an important step in the increasing adoption of using data-driven approaches to decision making.

This study aimed to determine whether construction material affected the severity outcome 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 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 to restrict the comparison to similar structures, as apartment buildings are usually better equipped with protective systems and may be built from wood or non-combustible materials.

Methodology

DATA OVERVIEW

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 construction material. The BCOFC provided the same information for just BC, spanning the years 2007 to 2019.

VARIABLES OF INTEREST

Outcome variables of interest were the variables for 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 lower, and the proportions of fires requiring extinguishment by fire department and spreading beyond the room of origin were lower. Independent variables of interest were 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. 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.

STATISTICAL ANALYSIS

Descriptive statistics, with 95% Wald's confidence intervals, were conducted by construction material and protection systems in place. Independent multivariable models were also conducted for each outcome of interest in order to determine whether 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 independent 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).

Results

NFID

There were 13,897 apartment fires recorded in the NFID dataset between 2005 and 2015 in the provinces of MN, AB, and BC. 9,711 of these fires occurred in apartment buildings between one and six storeys in height, with 962 (10%) reported in MN, 3,685 (38%) in AB, and 5,064 (52%) in BC. 969 (10%) occurred in buildings with both working sprinklers and smoke alarms, 700 (7%) in buildings with working sprinklers only, and 3,669 (38%) in buildings with working smoke alarms only, 7,687 (79%) occurred in buildings constructed from combustible materials, 311 (3%) occurred in buildings constructed from non-combustible materials, and 1,713 (18%) had unknown or missing data for construction material. These fires resulted in a total of 74 fatalities and 961 injuries, with 4,032 (42%) of fires requiring extinguishment by the fire department, and 1,950 (20%) of fires spreading beyond the room of origin.

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 PROTECTION SYSTEM AND CONSTRUCTION MATERIAL IN BC, AB, AND MN BETWEEN 2005 AND 2015

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]
Construction Material	Combustible	7687	0.8	11.1	43.6	20
			[0.6, 1.0]	[10.4, 11.9]	[42.4, 44.7]	[19.1, 20.9]
	Non-combustible	311	1.6	10.9	34.7	13.5
			[0.2, 3.0]	[7.5, 14.4]	[29.4, 40.0]	[9.7, 17.3]
Protection System	None	3061	0.8	12	47.2	29.6
			[0.5, 1.2]	[10.9, 13.2]	[45.4, 49.0]	[27.9, 31.2]
	Smoke alarm	3132	1.1	12	47.1	15
			[0.7, 1.5]	[10.9, 13.2]	[45.4, 48.9]	[13.8, 16.3]
	Sprinkler	622	0.5	7.2	36.2	17.5
			[0.0, 1.0]	[5.2, 9.3]	[32.4, 40.0]	[14.5, 20.5]
	Both	878	0.6	11.5	35.2	10.9
			[0.1, 1.1]	[9.4, 13.6]	[32.0, 38.4]	[8.9, 13.0]

Looking at raw comparisons between construction materials, buildings constructed from non-combustible materials faired 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 (see Table 1). For protective systems, 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. Injury rates were lowest when only sprinklers were present. There were too few deaths to adequately compare and for further modeling.

After adjusting for protective systems, fire severity outcomes between combustible and non-combustible materials patterns were different. Modeling of injury rate and the variables of interest demonstrated that, after adjusting for protective systems and building height, construction material did not have a significant association (see Table 2). In terms of the protective systems, sprinklers reduced the rate of injuries by 47%, while having smoke alarms only or having both smoke alarm and sprinklers did not have a significant association.

TABLE 2: RESULTS FROM THE NEGATIVE BINOMIAL REGRESSION MODEL SHOWING RATE RATIOS, WITH 95% CONFIDENCE INTERVALS, BETWEEN THE INJURY RATE AND VARIABLES OF INTEREST (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Rate Ratio (95% CI)
Material	Non-combustible > Combustible	0.921 (0.585, 1.449)
Protection	Smoke Alarm > None	0.978 (0.810, 1.181)
	Sprinkler > None	**0.534 (0.364, 0.784)**
	Both > None	0.836 (0.617, 1.134)
Height	**Per storey**	**1.151 (1.034, 1.282)**

Modeling of the odds of requiring extinguishment by fire department did not show significant association with building material, after adjusting for protective systems and building height (see Table 3). For the protective systems, having smoke alarms only reduced the odds of requiring extinguishment by fire department by 26%, having sprinklers only reduced odds by 39%, and having both reduced odds by 51%.

TABLE 3: 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 (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Odds Ratio (95% CI)
Material	Non-combustible > Combustible	0.852 (0.653, 1.112)
Protection	**Smoke Alarm > None**	**0.744 (0.666, 0.832)**
	Sprinkler > None	**0.613 (0.502, 0.749)**
	Both > None	**0.489 (0.411, 0.581)**
Height	**Per storey**	**0.823 (0.773. 0.876)**

Modeling of the odds of the fire spreading beyond the room of origin did not show significant association with construction material, after adjusting for protective systems and height of the building (see Table 4). For protective systems, having smoke alarms only reduced the odds of the fire spreading beyond room of origin by 60%, sprinklers only reduced the odds by 50%, and having both reduced the odds by 71%.

TABLE 4: 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 (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Odds Ratio (95% CI)
Material	Non-combustible > Combustible	0.917 (0.647, 1.301)
Protection	**Smoke Alarm > None**	**0.402 (0.354, 0.457)**
	Sprinkler > None	**0.500 (0.397, 0.630)**
	Both > None	**0.286 (0.225, 0.362)**
Height	**Per storey**	**0.855 (0.796, 0.918)**

BCOFC

There were 6,023 apartment fires recorded in the BCOFC dataset between 2007 and 2019 in BC. 4,474 of these fires occurred in apartment buildings between one and six storeys in height. 1,011 (23%) occurred in buildings with both sprinklers and smoke alarms, 564 (13%) occurred in buildings with working sprinklers only, and 1,734 (39%) occurred in buildings with working smoke alarms only. 3,539 (79%) occurred in buildings constructed from combustible materials, 260 (6%) occurred in buildings constructed from non-combustible materials, and 665 (15%) had unknown or missing data for construction material. These fires resulted in a total of 32 fatalities and 429 injuries, with 1,794 (40%) fires requiring extinguishment by the fire department, and 421 (9%) fires spreading beyond the room of origin.

Looking at raw comparisons between construction materials, buildings constructed from non-combustible materials faired better on all fire severity outcomes (see Table 5). For protective systems, the proportion of fires that spread beyond the room of origin were lowest when both sprinklers and smoke alarms were present. When only sprinklers were present, injury rate and proportion requiring extinguishment by fire department were at their lowest. There were too few deaths to adequately compare and for further modeling.

Similar to the NFID dataset, fire severity outcomes between combustible and non-combustible materials 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 height of the building, building material did not have significant association with injury rate (see Table 6). For protective systems, sprinklers reduced the rate of injuries by 42%, while the other comparisons did not have significant associations with the rate of injury in the event of a fire.

TABLE 5: 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 PROTECTION SYSTEM AND CONSTRUCTION MATERIAL IN BC BETWEEN 2007 AND 2019

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]
Construction Material	Combustible	3539	0.8	10.7	11.4	10.5
			[0.5, 1.1]	[9.7, 11.7]	[10.4, 12.5]	[9.5, 11.5]
	Non-combustible	270	0	5.2	5.2	4.8
			[0.0, 0.0]	[2.5, 7.8]	[2.5, 7.8]	[2.3, 7.4]
Protection System	None	994	0.4	12.6	13	15.3
			[0.0, 0.8]	[10.5, 14.6]	[10.9, 15.1]	[13.1, 17.5]
	Smoke alarm	1422	1.1	11.3	12.3	8.9
			[0.5, 1.6]	[9.6, 12.9]	[10.6, 14.0]	[7.4, 10.3]
	Sprinkler	500	1	6.2	7.2	7.8
			[0.1, 1.9]	[4.1, 8.3]	[4.9, 9.5]	[5.4, 10.2]
	Both	893	0.3	8.6	9	7.5
			[0.0, 0.7]	[6.8, 10.5]	[7.1, 10.8]	[5.8, 9.2]

TABLE 6: RESULTS FROM THE NEGATIVE BINOMIAL REGRESSION MODEL SHOWING RATE RATIOS, WITH 95% CONFIDENCE INTERVALS, BETWEEN THE INJURY RATE AND VARIABLES OF INTEREST (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Rate Ratio (95% CI)
Material	Non-combustible > Combustible	0.534 (0.282, 1.009)
Protection	Smoke Alarm > None	0.907 (0.668, 1.232)
	Sprinkler > None	**0.512 (0.317, 0.828)**
	Both > None	0.727 (0.501, 1.054)
Height	Per storey	0.977 (0.931, 1.147)

TABLE 7: RESULTS FROM THE LOGISTIC REGRESSION MODEL SHOWING ODDS RATIOS, WITH 95% CONFIDENCE INTERVALS, BETWEEN THE ODDS THE FIRE REQUIRING EXTINGUISHMENT BY FIRE DEPARTMENT AND VARIABLES OF INTEREST (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Odds Ratio (95% CI)
Material	Non-combustible > Combustible	1.051 (0.800, 1.380)
Protection	**Smoke Alarm > None**	**0.759 (0.643, 0.895)**
	Sprinkler > None	**0.675 (0.537, 0.848)**
	Both > None	**0.619 (0.511, 0.752)**
Height	**Per storey**	**0.895 (0.826, 0.970)**

Modeling of the odds of requiring extinguishment by fire department did not show significant association with building material, after adjusting for protective systems and building height (see Table 7). For protective systems, having smoke alarms only reduced the odds of requiring extinguishment by fire department by 24%, having sprinklers only reduced odds by 32%, and having both reduced odds by 38%.

Modeling of the odds of the fire spreading beyond the room of origin did not show significant association with building material, after adjusting for protective systems and building height (see Table 8). For protective systems, having smoke alarms only reduced the odds of the fire spreading beyond room of origin by 44%, sprinklers only reduced the odds by 44%, and having both reduced the odds by 45%.

TABLE 8: 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 (WITH SIGNIFICANT ASSOCIATIONS IN BOLD)

Variable	Comparison	Odds Ratio (95% CI)
Material	Non-combustible > Combustible	0.604 (0.337, 1.084)
Protection	**Smoke Alarm > None**	**0.563 (0.437, 0.726)**
	Sprinkler > None	**0.560 (0.383, 0.820)**
	Both > None	**0.545 (0.397, 0.747)**
Height	**Per storey**	**0.782 (0.683, 0.896)**

Discussion

This study included data on 9,711 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 4,474 fires reported to BCOFC in BC spanning the years 2007 to 2019. The results from analysis of the two datasets showed similar patterns, which was not surprising, as BC fires comprised just over half the fires (52%) analyzed from 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, construction material was found to not have a significant association with any of the fire severity outcomes of interest. This supports the gradual relaxation of height restrictions in buildings codes and the difference between the raw and adjusted comparisons was perhaps what led to the perception of wood structures being more dangerous. 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[16].

The protective systems were found to have different effects for different fire severity outcomes. Having working sprinklers reduced injuries, but having smoke alarm 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, resulting in more 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 had the largest protective effect. This may be because smoke alarms alert residents to combat the fire, whereas sprinklers role is to supress 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 supress 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 material would not play a role in the outcome of the fire, which may be a reason this study found that construction materials did not have signification associations with any of the fire severity outcomes after adjusting for protective systems. This is a limitation of 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, only a small proportion of these fires occurred in apartment buildings constructed from non-combustible materials (3% from NFID and 6% from BCOFC). Although indicating good performance, another limitation included having too few deaths for adequate comparisons and the lower numbers of injuries. Overall, these low counts resulted in larger confidence intervals, which may lead to false negatives. Other limitations in this study included the fact that many jurisdictions did not collect construction material as part of their fire reporting, resulting in only three provinces being included in the pan-Canadian analysis. There were also significant portions missing or unknown data in the variables of interest – the NFID dataset had significant unknown or missing information in construction material (18%), sprinkler (20%), smoke alarm (29%), fire department involvement (19%), and fire spread (12%), whereas the BCOFC dataset had significant unknown or missing information in construction material (15%), sprinkler (21%), and smoke alarm (16%).

Conclusions

This study is one of the first studies to look at the effect of construction material on the outcome of fires in the real-word environment. Across the Canadian provinces of BC, AB, and MN, the study found that, protective systems, in the form of smoke alarms and sprinklers, played a much greater role in reducing the severity outcome of a fire than construction material. 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.

Recommendations

This study highlighted the importance of protective 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 coverage is sufficient, and ensure they are well-maintained. Given the economic and environmental benefits of wood construction, this study supports the continued use of wood for taller structures. In the form of its limitations, this study also calls to attention the importance of quality and comprehensive data collection in the field, as multiple provinces and a significant number of fire events (around 30%) were excluded due to insufficient or missing data.

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