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ORIGINAL RESEARCH ARTICLE

Prevalence of indoor air pollutants from First Nation homes in North Central British Columbia, Canada

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ABSTRACT

Poor indoor air quality poses significant health risks. This study addresses the gap in knowledge regarding the prevalence of indoor air pollutants in remote and rural First Nation communities in north-central British Columbia, Canada. Dust samples from 75 homes were collected and analysed for house dust mites, pet allergens, mould antigens, and bacterial endotoxins. Indoor air quality parameters, including carbon monoxide, carbon dioxide, particulate matter, temperature, and humidity, were measured. A detailed questionnaire on household characteristics and potential pollutant sources was administered. Homes exhibited exposure to multiple pollutants, with wood stove smoke identified as a primary source. Felis domesticus (cat allergen) and Canis familiaris (dog allergen) were prevalent, with detectable levels in 64% and 60% of homes, respectively. Bacterial endotoxins were present in all households. One-third of homes exceeded recommended thresholds for 3 or more pollutants. This study provides critical insights into the prevalence and magnitude of indoor air pollutants, contributing to a broader initiative to characterise respiratory health in First Nations communities. While many homes in First Nations communities had acceptable air quality, one-third of homes exceeded thresholds for 3 or more pollutants. The results can guide ongoing community efforts to address housing concerns and advocate for increased federal funding.

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Introduction

The World Health Organization (WHO) reports that poor indoor air quality is a major health concern. Canadians spend approximately 90% of their time indoors [1] where the quality of air can be 2–5 times worse than outdoor air due to various pollutants [2]. Common indoor air pollutants include combustion particulates from cooking, tobacco, and burning fuels; antigens from dust mites, pet hair, and pollen; fumes from volatile organic compounds, synthetic fragrances, paint, chemical cleaners, and cosmetics; and endotoxins [2]. Activities such as cooking, washing and showering can cause condensation, which, combined with poor ventilation, can lead to mould and bacterial growth [2]. Homes that have structural defects can have higher levels of indoor air pollutants [3], as can homes with many occupants per square foot of space [4]. Exposure to indoor air pollutants can result in respiratory symptoms and disease [5].

Although all residential buildings are at risk for poor air quality, homes in Canada in rural communities may have higher risk for several reasons. First, approximately 60% of Canada's public road system is unpaved, and these roads primarily occur in rural and remote locations and communities [6]. Dirt roads increase airborne particulate matter [7]. Second, in many parts of rural Canada there is a reliance on wood stoves during the colder months which increases the risk of outdoor and indoor air pollution [8]. Third, wildfires are more prevalent in rural communities, and outdoor and indoor air quality can be drastically reduced during wildfire seasons [9].

First Nation communities in Canada contend with the challenges of rural housing as noted above, as well as the additional barrier of addressing their housing concerns within the limited funds provided by the federal government. Despite the responsibility of the federal government to provide financial support to maintain existing homes and build new ones, the support is far

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less than what is needed and many homes are in ill repair [10]. In response to these challenges, First Nation communities are partnering with researchers to better understand the air quality in their homes. For example, a 2005 study of a small sample of First Nation homes of children with asthma reported high levels of mould [11]. A 2023 study of 101 homes in 4 communities in northwestern Ontario, Canada, reported high levels of carbon dioxide in almost one-third of homes, and visible mould in almost half the homes [12]. However, previous studies of air quality in Indigenous populations in Canada were either based on self-report [10] or selectively tested homes based on convenience sampling [13] or requests from the community [12]. These methods might overestimate the prevalence of indoor air pollutants. In addition, there have been few studies in British Columbia (BC), with a larger number of communities participating.

First Nation communities throughout Canada require information on the indoor air quality of their members' homes, so they can target their home maintenance initiatives and advocate for appropriate levels of federal funding. This study on indoor air pollution is part of a larger initiative [14] to characterise the burden and risk factors of respiratory symptoms and lung disease in First Nations communities. In this study, we aimed to fill a gap in knowledge by estimating the prevalence of selected indoor air pollutants in residential buildings in remote and rural First Nation communities in north-central British Columbia (BC), Canada, using direct measurements of air pollutants and random-sampling of households.

Research methods

This study is a partnership between Carrier Sekani Family Services (CSFS), the University of British Columbia (UBC), and 8 First Nation communities (7 distinct Nations). These communities are located in north-central BC (Figure 1). CSFS is a First Nations-led organisation that provides holistic health, social, research and legal services to 11 First Nations. In June 2016, prior to initiating the study, CSFS and UBC (Holyk and Camp) hosted a meeting with representatives of each participating community to discuss lung health and community information needs. The First Nation community leaders agreed to the initial study objective of measuring metrics of lung health [14] and suggested the research be expanded to include measurement of indoor air pollutants due to concerns regarding indoor air quality (mould specifically) and its impact on lung health. In keeping with the principles of community-based research, the requirements of the community were respected, and indoor air quality measurement was included in the study design. The lead investigators for the grant (Camp, Holyk, and Bartlett) represent UBC and CSFS, and the research staff included members from both organisations. This process was in-line with CSFS (https://www.csfs.org/research/ethics) and the First Nations Information Governance Centre Ownership, Control, Access, and Possession (OCAP) research principles (https://fnigc.ca/ocap-training/). Ethics approval was received by both CSFS and UBC (CSFS October 2017; UBC #H16–03372, UBC Biosafety #B17–0125).

Households were sampled in the following manner. Each community provided a household list to the research team, and the team assigned each household a number. A computer random number generator selected potential households. We then visited each community and invited residents in those households to participate. Some of the participating First Nations communities in this study were within or near rural towns, while others were more isolated. In some instances, we also sampled homes that were not on our random-sampled list at the request of leadership in the First Nation community or the health centre, in alignment with participatory, community-led Indigenous research principles. These requests were not because there was a suspicion of poor air quality, but rather that there was an interest in participation in other aspects of the larger study (specifically, lung function and respiratory questionnaire measures). Written, informed consent was obtained from household residents for home visits and data collection. Houses were sampled in the winter months between 2017 and 2020.

Participants completed their informed consent and their questionnaires in the community health centre. Then, they took us to their homes for the air quality assessment, dust sampling, and home inspection. These visits occurred between 10 am and 3 pm, Monday to Friday. This off-peak timing reduced the likelihood of cooking or showering occurring, the use of candles or the presence of many family members who may stir up the dust. Residents did not smoke during our visits, but given the winter season wood stoves were often in use. In addition, due to the impromptu nature of the visits, members did not have a chance to "clean up" prior to our visit, which reduced the risk of increased airborne particulate matter prior to sampling.

Mould, antigen, and endotoxin

In each home, we collected settled dust samples, typically from a bedroom, the living room, and an additional room, such as a basement room. Approximately 15 mg of dust was collected from each room using a portable vacuum fitted with a sampling sock with a

Figure 1. Map of British Columbia, Canada. The participating communities were located within the section marked in red.

pore size of 5–10 µm. Each room constituted a unique dust sample, and the sampling sock was sealed in a separate ziplock bag, kept cool during transport, and analysed in the laboratory at the University of British Columbia (UBC).

All dust samples were processed using established protocols [15]. Dust samples were extracted in 005% Tween 20 in phosphate-buffered saline at pH 7.4 using certified pyrogen-free water (Lonza, Walkersville, MD). All samples were analysed in duplicates and standards in triplicates. Bench work was carried out in the biological safety cabinet to avoid or minimise contamination. The dust samples were assigned a laboratory number, weighed and sieved to retain materials <300 µm. The samples from each room were combined into one sample for analysis. The extracted dust, obtained from the process, contained 100 mg/2 ml of 0.05% Tween 20 in pyrogen-free phosphate-buffered saline at pH 7.4. It was aliquoted and stored at −20°C for subsequent analysis.

Dust samples were examined for antigen content using pre-coated, ELISA 2.0 Quantitative Allergen Immunoassay Kits supplied by Indoor Biotechnologies, Charlottesville, VA, as per established protocols [16]. The same house dust sample was examined for the presence and amount of antigens, specifically house dust mite *Dermatophagoides pteronyssinus* (Der p1) and *Dermatophagoides farina* (Der f1), *Felis domesticus* (Fel d1), *Canis familiaris* (Can f1), mouse *Mus musculus* (Mus m1), and mould *Alternaria alternata* (Alt a1) and *Aspergillus fumigatus* (Asp f1). The limit of detection of ELISA antigen determination was 0.4 ng/mL extract.

Briefly, following the manufacturer's instructions, standard curves were constructed in the 96-well microtiter plates using purified antigen serially diluted in supplied assay buffer. Duplicate aliquots of 20 µL extracted dust samples were made to 100 µL in supplied assay buffer. After 1 hour of incubation at room temperature, plates were washed, and detection

antibody-streptavidin-peroxidase was added to each well and incubated for 1 hour. Plates were washed, and 3.3′5.5′-Tetramethylbenzidine (TMB) was added. Optical density was monitored until the highest standard reached 0.08–0.09 at $OD_{450,}$ at which time stop solution was added. Plates were then read using a Molecular Devices SpectraMax190 microplate reader. Target values for the highest standards fell between 1.2 and 3.5 at OD_{450}. QA/QC was determined for every assay by assessing the R^2 of the standard curve, the precision of the triplicates (standards) and duplicates (samples) and the blanks.

Endotoxin in dust samples were analysed using established protocols [17,18]. We used a Kinetic Limulus Amoebocyte Lysate (LAL) Assay (Lonza Kinetic QCL, Walkersville, VA) and standard curves (50 EU/mL –0.049 EU/mL) were constructed using serial dilutions of the reconstituted endotoxin standard supplied with the kit. The extracted dust samples were diluted 1:100 and 1:1000 for analysis in duplicate. LAL reagent was added to each well, and the kinetic assays proceeded at 37°C, with readings taken every 30 s at OD_{405}. Samples were evaluated against Vmax of standards. The R^2 of the standard curve was determined to exceed 0.995. The QA/QC was determined from the precision of the duplicated samples and standards, and the blanks.

Carbon monoxide, carbon dioxide, particulate matter, relative humidity, and temperature

We conducted indoor air sampling in occupied residences under closed-door conditions to ensure airflow stability and achieve reproducible measurements. Sampling occurred from late fall to early spring (October–April). Simultaneous, real-time measurement of carbon monoxide (CO), carbon dioxide (CO_2), temperature, and relative humidity (RH) was done with a Q-Trak monitor (TSI Incorporated; Shoreview, Minnesota) with the 982 Indoor Air Quality probe. The air was sampled with the monitor for 5 min, with at least 1–2 people nearby to generate approximate occupancy CO_2 concentrations. Particulate matter was measured with a handheld particle counter (Kanomax; Andover, New Jersey), with a 5 min sampling time. Monitors were placed at table height in 3 rooms per home – typically, the living room, a bedroom and one additional room. These measurements were taken before vacuuming for dust samples in order to minimise disturbing the settled dust. The smallest particle size bin that can be measured with the Kanomax is <0.3 µm/m^3. The analytical limit of detection was taken into consideration, and values falling below the detectable ranges of both the Kanomax, Q-Trak, and the molecular device Spectramax 190 microplate reader were treated as zero values.

The Q-Trak monitor undergoes an annual full instrument calibration at the TSI facility (Minnesota, USA). At the beginning of each community trip, we calibrated the system for CO_2 to 1000 ppm and 25 ppm for CO, using tanks of Zero Air and CO blend. The Kanomax system undergoes an annual full instrument calibration at the Kanomax facility (New Jersey, USA). No other calibration is required during community visits. The Kanomax system completes a cleaning cycle after each measurement.

Household characteristics

We administered an interviewer-facilitated questionnaire comprised of items from the United States General Services Administration checklist for the routine inspection of the building [19] and previous bioaerosol work in First Nation's communities [20] to assess the presence and use of exhaust vents, signs of uncontrolled moisture, occupancy levels, pet ownership, types of flooring, heating energy (natural gas, propane, oil, wood, or electricity), areas where repair may be warranted, and the use of indoor combustion appliances in residential buildings. Residents also added additional details on their homes, including the need for repairs, any signs or smells of mould in the house, the presence of pets, and the occupants' current smoking behaviours.

Data analysis

In most cases, air quality measurements, dust samples, and questionnaire information were collected during the same visit. The collected data was entered in REDCap (Research Electronic Data Capture, US), double-checked for accuracy, and was analysed using the Statistical Package for Social Sciences (version 28; IBM Corp., US). Samples from a given home were combined for analysis. We used means, standard deviations, ranges and medians for continuous data, and counts and proportions for categorical data to describe demographic characteristics, indoor air pollutants, and building characteristics. We dichotomised households as exceeding pre-established target values for antigens [21–24], endotoxins [18,25], highest quartile of $PM_{3.0}$, CO [26], CO_2 [27], RH [27] and temperature [28,29].

Results

Description of community characteristics

Data was collected from 75 homes (randomised = 61, non-randomised = 14) in eight communities. Two communities were located within the geographical area of a non-First Nations rural town. The other 6 communities

were in more isolated locations. Most communities were forested with dirt roads.

Normality testing was conducted separately for both sets of data, revealing a non-parametric distribution for each. The addition of non-randomised data to the randomised data did not influence the analysis outcomes. Consequently, the dataset of 75 samples was analysed together. Data collection occurred between October 2018 and March 2020. In northern Canada, these months typically coincide with winter weather. The median outdoor temperature was 1°C (IQR: −17°C to 18°C). Many houses were snow-covered during the assessment. All homes were located in remote or rural communities, with fewer than 500 households per community. Some communities had less than 20 households.

Homes were of wood frame construction with poured concrete foundations. Some homes had below-grade basement levels. Most homes were two-level, with the lower level used as a basement or additional sleeping area. House cladding was primarily vinyl siding; however, newer homes often had cement board siding. Roofs were predominantly asphalt (80%) and windows were primarily double-paned. Homes were typically less than 60 years old.

Table 1. Household characteristics ($n = 75$).

	Information Source	n	%
Someone smokes in the house	Self-Report	24	32%
Presence of any pet in the house	Self-Report	43	57%
Presence of just dogs in the house	Self-Report	21	28%
Presence of just cats in the house	Self-Report	15	20%
Presence of both dogs and cats in the house	Self-Report	7	9%
Resident reports musty or mouldy smell	Self-Report	28	37%
Resident reports home needs repair	Self-Report	51	68%
Use of cooking heat source other than electricity	Self-Report	8	11%
Number of occupants, mean (range)	Self-Report	3 (1 to 7)	
Presence of carpets in at least 1 room	Observed	13	17%
Presence and use of functional kitchen fans	Observed	55	73%
Presence and use of functional bathroom fans	Observed	59	79%
Presence of wood stove in the house	Observed	57	76%
Presence of Heating, Ventilation, and Air Conditioning (HVAC)	Observed	50	67%
Roof elements (gutters, flashing) need repair	Observed	67	89%
Exterior walls need repair	Observed	39	52%
Doors or windows need repair	Observed	26	35%
Foundation needs repair	Observed	1	1%
Home needs at least 1 repair of: kitchen fan, bathroom fan, roof elements, exterior walls, doors/windows, or foundation	Observed	72	96%

Potential sources of pollutants

All homes had exposure to pollutants (Table 1). Residents reported that the primary source of outdoor air pollutants in the winter was wood stove smoke and in the summer was wildfire smoke. Wood was the most commonly used source of heat (76%), with woodstoves typically in use. Some homes had wood pellet furnaces. Central heating and/or cooling systems were installed in 67% of the households. Ventilation fans were installed in all homes, but only 73% and 79% reported having and using functional kitchen and bathroom fans, respectively. Thirty-two per cent of homes had at least 1 cigarette smoker. Indoor pets were reported in 57% of homes, with dogs in 28%, cats in 20%, and both in 9%. Sixty-eight per cent of residents noted their homes needed repairs, with home inspections revealing that 96% of homes required at least 1 repair. Thirty-seven per cent of respondents reported a musty or mouldy smell in their homes, but only 3% of homes had signs of dampness.

Indoor pollutants

Table 2 shows the mean (SD) and range values of each pollutant, and Table 3 shows the proportion of households that exceeded target levels. *Felis domesticus* was the most prevalent (detectable in 64% of homes) with a mean (SD) of 2.0 ng (9.9 ng). Homes with cats had the highest levels, but this antigen was also detected in 31 homes without cats. *Canis familiaris* was detected in 60% of homes; households with dogs had the highest levels but was present in 20 households without dogs. Mouse antigen and house dust mite antigen and *Aspergillus fumigatus* had negligible levels, and *Alternaria alternata* was not detected in any of the household dust samples. Bacterial endotoxins were detected in all households, with a mean of 81.8 EU/100 mg dust (74.2 EU/100 mg).

The mean count of $PM_{3.0}/m^3$ was 116 347 (69 575). Mean CO_2 was 891 ppm (311 ppm). Of the 75 houses, 25% had CO_2 levels above 1000 ppm, indicating poor ventilation. CO levels were below target levels of exposures with a mean of 0.19 ppm (0.19 ppm), with 88% of households having detectable amounts. The mean indoor temperature and relative humidity were within the recommended ranges. While the majority of homes had acceptable levels of individual air pollutants, approximately one-fourth to one-third of homes exceeded the recommended target values of individual pollutants, and one-third of homes exceeded three or more target values (Table 4).

Discussion

This cross-sectional study estimated the prevalence of selected indoor air pollutants in homes located in First Nations communities in north-central British Columbia.

Table 2. Indoor air pollutants or environmental variables.

	Mean (SD)	Range
Felis domesticus (*Fel d1*), ng/mg dust	2.0 (9.9)	0 - 84.1
Canis familiaris (*Can f1*), ng/mg dust	2.4 (6.6)	0 - 48.8
Dermatophagoides pteronyssinus (*Der p1*), ng/mg dust	0.2 (1.5)	0 - 12.50
Dermatophagoides farina (*Der f1*), ng/mg dust	0.000012 (0.0001)	0 - 0.0009
Mus musculus (*Mus m1*), ng/mg dust	0.03 (0.19)	0 - 1.56
Alternaria alternate (Alt a1), ng/mg dust	0.00	-
Aspergillus fumigatus (Asp f1), ng/mg dust	0.003 (0.014)	0 - 0.09
Bacterial endotoxin, EU/100 mg dust	81.8 (74.2)	9.4 - 229.8
Particulate matter, counts <3.0 µm/m^3 (PM3.0/m^3)	116 347 (69 575)	11 102 - 245 347
Carbon dioxide (CO_2), ppm	891 (311)	520 - 2 171
Carbon monoxide (CO), ppm	0.19 (0.19)	0 - 0.83
Relative humidity (RH) (%)	34.7 (9.3)	17.9 - 59.9
Temperature (°C)	22.5 (1.9)	18.7 - 30.2

Fel d1 = *Felis domesticus;* SD=standard deviation; Can f1 = *Canis familiaris;* Der p1 = *Dermatophagoides pteronyssinus;* Der f1 = *Dermatophagoides farina;* Mus m1 = *Mus musculus;* Alt a1 = *Alternaria alternata;* Asp f1 = *Aspergillus fumigatus;* EU = Endotoxin unit; ppm = parts per million; CO_2 = carbon dioxide; CO = carbon monoxide; RH = relative humidity.

Table 3. Pollutants and target values.

Variable	Target values (based on peer-reviewed literature or regulatory body)	Houses exceeding the target value, n (%)	Range of values for houses exceeding target values
Antigen level	>2 ng*	26 (35%)	2.23 - 84.10 ng
Endotoxin level	>100 EU/100 mg**	29 (39%)	116 - 230 EU/100 mg
Particulate matter (counts PM <3.0 µm/m^3)	Households the highest quartile	19 (25%)	170 206 - 245 347 counts
Carbon monoxide (CO) level	>3 ppm †	0 (0%)	-
Detectable carbon monoxide (CO)	>0 ppm	66 (88%)	0.03 - 0.83 ppm
Carbon dioxide (CO_2) level	>1000 ppm ††	19 (25%)	1017 - 2170 ppm
Relative humidity (RH) (%)	>60% ‡	0 (0%)	-
Temperature (°C)	≥26°C or ≤ 18°C ‡‡	3 (4%) above 26 °C 0 (0%) below 18 °C	26°C – 30 °C

EU= Endotoxin units; PM = particulate matter, CO = carbon monoxide, CO_2 = carbon dioxide; RH = relative humidity, °C = degrees Celsius.
*Antigen target value based on Peng et al. [21], Ahluwalia et al. [22], Hollander et al. [23], and Heederik et al. [24].
**: Endotoxin target value based on Health Council of the Netherlands [25], Hansen et al. [18].
†Carbon monoxide target value based on United States Environmental Protection Agency [26].
††Carbon dioxide target value based on American Society of Heating, Refrigeration and Air-Conditioning Engineers [27].
‡Relative humidity target value based on American Society of Heating, Refrigeration and Air-Conditioning Engineers [27].
‡‡Temperature target value based on Tham et al. [28], Janssen et al. [29].

Table 4. Proportion of households exceeding one or more target values.

Number of pollutant target values exceeded	Proportion of households that exceeded each number of target values – n (%)
0	2 (3%)
1	20 (31%)
2	28 (33%)
3	15 (20%)
4	9 (12%)
5	1 (1%)
6	0 (0%)
7	0 (0%)
8	0 (0%)

This study was motivated by First Nations communities' and Carrier Sekani Family Services' need for detailed and accurate information on the air quality in homes, in order to increase community knowledge, target remediation, and explore prevention strategies. This need was articulated through an extensive community engagement process, as per CSFS (https://www.csfs.org/research/) and OCAP (https://fnigc.ca/ocap-training/) best practices, during which community members approved a study to measure lung function and characterise lung health (which will be reported in a subsequent manuscript) as long as measures of indoor air quality were included. A socioecological perspective of health [30] moves the research beyond studies of individual behaviours and symptoms and explores other elements of exposure, such as indoor air quality.

With respect to houses in First Nation communities, news media often portray housing in First Nations communities in a homogeneous fashion, with the housing stock portrayed as "in crisis" (e.g. CTV News, 30 January 2019, https://www.ctvnews.ca/politics/mould-causing-housing-crisis-for-first-nations-across-canada-ndp-1.4275635?cache=njqqxnnujf). Our findings suggest that the true picture in some communities is more nuanced – there are many homes with

acceptable levels of individual indoor pollutants, but a substantial proportion of homes have multiple pollutants which may warrant targeted attention.

It is important to note that all homes have indoor air pollutants, regardless of setting. Numerous primary studies [15,31–33], systematic reviews [34,35] and statements [36] have documented the source, prevalence, and amount of various air quality pollutants found in residential homes throughout the world. Two recent systematic reviews [37,38] reported that building materials, proximity to outdoor pollution sources such as dusty roads, building ventilation components, cooking fuel, household size, indoor finishing materials, and individual behaviours such as cigarette smoking are important contributors to indoor air quality. In this study, we identified several characteristics in the homes we sampled that contributed to worse air quality, including cigarette smoking, indoor pets, and non-working fans.

When pollutants reach a certain level, there is cause for concern. A key finding in this study was the high prevalence of endotoxins. Endotoxins are toxic substances in the cell walls of gram-negative bacteria. Exposure to high endotoxin levels in indoor dust increases the risk and severity of asthma symptoms [39–42], a finding reported in several studies, including one of American homes and child care centres (Wang 2022) and Indigenous homes in remote communities in Northwestern Ontario, Canada [15]. In these communities, endotoxins could have been introduced to the households in many ways, such as from compost material, pests, or individuals walking in the house with shoes worn in outdoor spaces. Almost half of households had endotoxin levels considered high enough to cause an inflammatory response in the airways and subsequent respiratory symptoms, including cough and wheeze [39–41,43,44]. Pets, rodents, and vermin are usually associated with high endotoxin levels in house dust [42,45] and 56% of households had pets in this study.

Alternaria alternata was not detected, and the low prevalence of house dust mite and mouse antigen, as well as *Aspergillus fumigatus,* may be attributed to the region's dry climate during the winter seasons. Only 3% of the households had signs of dampness, which usually provides conditions conducive to mould growth given optimum temperature and humidity. An important household characteristic was that only 17% of the households had carpets, which are typically the environment of dust mites [46]. Indoor relative humidity values between 40% and 50% are associated with low mite levels [47] and only 5 homes (6%) had humidity values above 50%. This is in contrast to a study of indoor air quality in Indigenous homes in New Zealand, where relative humidity was consistently above 80%. Our average RH value of 34.7% was similar to studies in similar environmental locations, including a study [48] of Alaska Native homes that reported a median RH of 23% and a nationwide Swedish study [49] of 1400 homes which reported that the majority of homes had a RH value <51%.

The major indoor sources of PM are smoking, cooking, wood stoves, and pets [50]. Cooking emissions in the absence of a sound ventilation system is a source of relatively high indoor particles concentration, confirmed in a residential demonstration study [51], as well as a study done in northern Indigenous communities in Quebec, Canada [52]. Particulate matter exposure is associated with worse health outcomes, including exacerbation of existing respiratory or cardiac disease [34]. A 2021 systematic review [34] of 69 studies from Asia, the Americas, Africa and Europe reported an association between PM2.5 and markers of airway inflammation in people with asthma, as well as reductions in lung function and an increase in symptoms in people with COPD. In the context of Indigenous community settings, burning of wood for heating and $PM_{2.5}$ have been documented to have an association with respiratory symptoms in Alaska Indigenous children study [53]. The particulate matter measures in the current study were similar to those reported in a study done in remote communities in northwestern Ontario, Canada [15]. These findings could be attributed to the use of wood stoves, a high prevalence of cigarette smoking in the houses, and poor ventilation, especially when cooking.

Although some homes had levels of pollutants that exceeded our pre-determined target values, there were several notable features in the homes we sampled that may have contributed to *better* air quality. Very few homes had carpeted rooms, and those that did typically only had 1 or 2 rooms with carpets. This may have reduced exposure to dust, antigens, and endotoxins. Most homes used electricity for cooking, which is a clean source of energy compared to natural gas [54]. Overcrowding was not a feature in these homes, in contrast to a recent study of First Nations homes in Ontario, Canada [12]. The northern location meant that dusty roads were covered with snow for several months of the year, reducing dust exposure, and the rural location reduced exposure to other outdoor pollutants such as traffic pollution or pollution from industry.

Strength and limitations

This study had several strengths. The project was enabled by the partnership between CSFS, UBC and member Nations, resulting in the development of research questions that supported the needs of the communities. We collected data from households that were primarily randomly sampled, which allowed for more representative estimates. Samples were collected during the winter season to avoid underestimation of exposures due to greater ventilation,

which tends to occur during warmer months (e.g. doors and windows open). We used high-quality analytical tools to analyse indoor air pollutants with recommended quality controls. Limitations include the possibility of recall bias with self-reporting of potential exposure risk factors. The 5-min sampling period for particulate matter, CO, CO_2, temperature and humidity may not accurately represent the true levels in a home over a longer time period. The duration of indoor air pollutant exposures was not assessed, therefore it is difficult to determine how long the participants have lived in the household or have been exposed to a particular indoor air pollutant.

Future plans

The next step for this work includes responsible knowledge translation to community members. The presence of some air quality pollutants is expected and normal, and therefore it is important to share these results truthfully and responsibly while not creating undue panic for residents or hardship for First Nations leadership responsible for repairs. Many participants did comment on musty smells and the need for repairs. Individualised community reports that summarise the air quality of the sampled homes and identifies which homes require remediation will support leadership decision-making.

Housing features that need repair may increase the levels of pollutants or decrease them. For example, a broken window may increase the risk of water ingress and subsequent mould development, but it could also increase ventilation. Increased pollutants in a house are due to a complex interplay of designed housing features, repair needs, and the number and activities of the occupants.

Mitigation strategies may include ensuring ventilation fans are functioning and wood stoves are properly sealed, and targeting structural repairs on specific homes. In one community, remediation has already occurred based on the findings of this study.

Conclusion

The purpose of this study was to estimate the prevalence of selected indoor air pollutants in homes in remote and rural First Nation communities. In many BC First Nations homes, the Government of Canada retains the legal title to the land where a home is located, and the resident is issued a Certificate of Possession, which allows the individual to own their home, but limits their ability to apply for a mortgage. First Nation communities can apply for federal funds for housing repairs, but there are limits to that support requiring communities to allocate funding based on their criteria. We found that majority of homes were exposed to 4 or more pollutants, but most homes' exposures did not exceed target values. First Nations communities have worked diligently to improve housing for their members, and the results of this study show that many homes have acceptable air quality. However, one-third of homes exceeded target levels of three or more pollutants, which warrant mitigation efforts. As communities continue to advocate for increased funding for housing from the Canadian government, the results from this study provide them with the necessary details on the prevalence and magnitude of indoor air pollutants in community homes.

Disclosure statement

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