Young First Nations (FN) children in Canada have high rates of lower respiratory tract infections (LRTIs), including bronchiolitis and pneumonia, with 44 hospital admissions for LRTI per 1000 infants younger than 1 year living in the Sioux Lookout FN Health Authority (SLFNHA) region of northwestern Ontario, compared with 25 per 1000 in the general population, although rates are higher among Inuit infants in Nunavut (235 per 1000).1,2

Adverse respiratory health outcomes have been associated with poor indoor environmental quality (IEQ) worldwide.3,4 Surveys have found that more than 24% of FN and Inuit housing is overcrowded or in need of major repairs or both, compared with 6% elsewhere in Canada.5 Issues related to IEQ are anecdotally reported to be common.6,7 Few studies have quantified IEQ in FN housing, and most have focused on road-accessible communities.8–11 We evaluated IEQ and respiratory morbidity in the homes of young children in 4 FN communities receiving health services from SLFNHA. Three communities were accessible only by air or winter road. We hypothesized that poor IEQ would be associated with respiratory morbidity in this population.

Methods

Study design and participants
We performed a cross-sectional study of IEQ and respiratory morbidity in Lac Seul FN, Kasabonika Lake FN, Sandy Lake FN and Kitcenuhmaykoosib Innuwinug FN. We chose communities based on size (to minimize cost), a variety of rates of LRTI and local recommendations.1 We aimed to survey about 25 houses per community. We did not select houses randomly, but given the small population of these communities (about 1200 people per community), our convenience sample included approximately 40% of eligible houses.12,13
Protocol-specified inclusion criteria were parental self-identification as FN and age 3 years or younger. We removed both newborns and children who had recently moved into a house with IEQ measurements from data analysis owing to insufficient IEQ exposure or minimal health outcome data (Figure 1). When there were multiple eligible children in the household, we selected the youngest eligible child, as LRTI is commonest in the first year of life.14

Community engagement
Community selection was guided by SLFNHA. We obtained community support from the SLFNHA Chief’s Committee on Health and the leadership of each community — including Chief and Band Council, the Community Health Representative and the Housing Manager — and raised community awareness through local radio phone-in shows. Community groups identified concerns about eczema and skin infections and requested that we evaluate potential associations with IEQ. These findings will be reported separately.

We recruited a community-based research coordinator (typically the Community Health Representative) to help identify eligible houses, administer surveys and provide translation. Study participants received a written report comparing their household measurements to community averages, along with targeted remediation measures. We shared reports with aggregate results with SLFNHA and the Chief and Council of participating communities. We shared housing issues of immediate safety concern with the local Housing Manager.

Data collection
The research coordinator administered a validated respiratory health questionnaire.13 A pediatric respirologist (T.K.) reviewed participant medical health records at community nursing stations for respiratory illness(es).

An indoor air quality specialist and team member documented housing characteristics, including calculation of surface area of visible mould (SAM), using standardized protocols developed in previous Health Canada studies.15,16 When crawlspaces could not be safely entered, and there was evidently heavy surface mould contamination, we coded SAM as more than 0.2 m². We defined presence of overcrowding as more than 1 person per room, excluding bathrooms.5

We deployed air monitoring equipment for 3–5 days in the main living area (Appendix 1, available at www.cmaj.ca/lookup/doi/10.1503/cmaj.202465/tab-related-content). We logged particulate matter 2.5 (PM2.5) concentrations by laser photometry and an in-line filter to collect corresponding gravimetric measurements. We also analyzed filters for levoglucosan,10,17-20 a major constituent of wood smoke.21 We used a carbon dioxide (CO2) sensor attached to a data logger to measure CO2, with a second logger to collect temperature and relative humidity (RH). We also measured these in a central outdoor location in each community. We measured formaldehyde and acetaldehyde with passive samplers and captured volatile organic compounds (VOCs) using thermal desorption tubes.

We collected settled dust samples from the living room floor, typically from 1–2 m² of flooring. We sieved the dust after storing it in a dry location and analyzed dust fraction < 300 µm for endotoxin, house dust mite allergens and 1,3-β-D-glucan, used as an indicator of fungal load. We extracted and measured the dust mite allergens Der f1 (Dermatophagoides farinae) and Der p1 (D. pteronyssinus).22 We calculated glucan and endotoxin load by dividing their weights by the surface area of flooring vacuumed (m²).23,24 We carried out IEQ monitoring during the cold weather season when doors and windows are typically closed, and indoor contaminant concentrations are typically highest.

Outcomes
The primary study outcome was LRTI, and the secondary outcomes were upper respiratory tract infection (URTI) and wheeze with colds (based on questionnaire reporting).

Covariates and variables
To minimize type I errors and ensure model stability given constraints of sample size, we decided a priori which variables we would use to examine associations between IEQ and health. We chose total SAM and settled dust glucan as markers of mould exposure; PM2.5, indoor CO2 as a proxy of indoor ventilation, and settled dust endotoxin. We included commonly recognized risk factors for LRTI (prematurity and age) in multivariable analyses as potential confounders.25

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Figure 1: Consolidated Standards of Reporting Trials (CONSORT) flow chart showing flow of participants through the study. Note: CO2 = carbon dioxide, FN = First Nations, PM2.5 = particulate matter < 2.5 µm. *Number of participants approached is somewhat approximate for 2 of 4 communities. †Actual sample size depends on each model (see tables).
Statistical analysis
Given minimal pre-existing data available on IEQ and pediatric respiratory morbidity in Canadian FN communities, we could not estimate sample size requirements. 1 Although we had previously observed significant associations between CO₂ and LRTI in 49 young Inuit children, LRTI rates are much higher in Nunavut. 1,13 We compiled exposure data using SAS, merged them with health and questionnaire data in an Excel spreadsheet and transferred them to R for analyses. 26,27 We summarized data using means with standard deviations (SDs) as well as medians with interquartile ranges, as several variables were skewed. We described categorical variables using frequencies and percentages. We reported outcomes that were measured during visits as event rates annualized per child’s years of life; otherwise, we reported them as a binary (yes or no) outcome. We transformed the covariate endotoxin using the natural logarithm given its skewed distribution. For covariates that were found to have a nonlinear association with an outcome, we included a 3-knot restricted cubic spline in the model. We used multivariable negative binomial regression with an offset given by the log age to model outcomes expressed as event rates (LRTI and URTI). We used multivariable logistic regression to model the outcome of wheeze with colds, which was a binary variable. We included age as a predictor in each of the models. We dichotomized SAM as being above or below 0.2 m². 28 Because some values of covariates were missing (Appendix 2, Table S1, available at www.cmaj.ca/lookup/doi/10.1503/cmaj.202465/tab-related-content), we ran regression modelling using complete cases; we carried out sensitivity analyses using multiple imputation with chained equations and predictive mean matching using the R package MICE with 50 iterations. 29 Given that about 17% of records had at least 1 missing value, we used 17 imputations. 30

Ethics approval
We obtained Research Ethics Board approvals from Health Canada, the Children’s Hospital of Eastern Ontario (CHEO), the Ottawa Hospital, and the Sioux Lookout Meno Ya Win Health Centre. We developed the study under the guidance of the Nishnawbe Aski Nation and SLFNHA. Permission was granted by SLFNHA and each participating community. Although data resided at CHEO, the Nishnawbe Aski Nation had full access to the data, and participated in data analysis and interpretation of results.

Results
Characteristics of the participants and their housing
We recruited 103 participants, from 102 houses, into the study. We subsequently excluded 5 participants for protocol violations, leaving 98 participants for descriptive analysis. There were complete data for analyzed covariates for 81 participants, who were included in the multivariable analyses (Figure 1).

Participant and house characteristics are provided in Table 1. The sample size represented about 21% (98/478) of eligible children. 32 Participants had a mean age of 1.6 years (SD 1.0; range 0.08–3.91 yr [Table 1]). Fifty-one (52%) were male. Indoor commercial tobacco smoking was prevalent, with 1 or both guardians smoking in 94% (88/94) of houses. The median number of smokers per house was 2.0 (range 0–7).

Houses had a mean heated house volume of 243.2 m³ (SD 114.1) and most were crowded, with a mean occupancy of 6.6 (SD 2.6, range 3–17) people per house (Table 1 and Table 2). In comparison, the typical volume of a smaller house in southern Canada is 350–400 m³ and 400–600 m³ for a medium-sized house, and the average household size in Canada is 2.5 people. 22,31 Household concerns identified during the inspections included lack of controlled ventilation with a heat recovery ventilator (HRV) because the device was absent, not working or

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Table 1: Characteristics of the houses visited, n = 98 participants

| Exposure variable | No. (% of participants) | No. (%) of missing variables |
|-------------------|-------------------------|-----------------------------|
| Location          |                         |                             |
| Big Trout Lake    | 21 (21)                 | 0 (0)                       |
| Kasabonika        | 24 (24)                 | 0 (0)                       |
| Lac Seul          | 22 (22)                 | 0 (0)                       |
| Sandy Lake        | 31 (32)                 | 0 (0)                       |
| Average heated volume, m³, mean ± SD | 243.2 ± 114.1 | 0 (0) |
| No. people in house, mean ± SD | 6.6 ± 2.6 | 0 (0) |
| Range             | 3–17                    |                             |
| People/room (excluding bathroom), mean ± SD | 1.4 ± 0.5 | 0 (0) |
| Crowding (> 1 person/room) | 63 (64) | 0 (0) |
| Type of heating fuel |                         |                             |
| Wood and electricity | 71 (72) | 0 (0) |
| Electricity only  | 15 (15)                 | 0 (0)                       |
| Other             | 12 (12)                 | 0 (0)                       |
| Guardian smokes   |                         |                             |
| Male              | 76 (89)                 | 13 (13)                     |
| Female            | 73 (74)                 | 0 (0)                       |
| Either            | 88 (94)                 | 4 (4.1)                     |
| Houses lacking potable water | 32 (33) | 0 (0) |
| Controlled ventilation fan | 43 (44) | 1 (1) |
| Use of fan always or sometimes | 15 (16) | 2 (2) |
| Working range hood fan | 52 (53) | 0 (0) |
| Range hood fan in bathroom | 44 (45) | 0 (0) |
| Reported an episode of flooding in home | 47 (48) | 0 (0) |
| Signs of water penetration in exterior walls | 43 (44) | 0 (0) |
| Exterior signs of water penetration in windows | 44 (45) | 0 (0) |

Note: SD = standard deviation.
*Unless otherwise specified.
not used in 85% (83/98) of houses; signs of water penetration in exterior walls in 44% (43/98); immediate safety issues (including extreme fire hazard, electrical hazard or shifting of the house in 6 houses (6%)) (Table 3); and damaged windows (including broken windowpanes and moisture-damaged frames or sills) in 51% (50/98).

Characteristics of indoor environmental quality

Characteristics of IEQ variables are provided in Table 2. The mean living room temperature was 25.6°C (SD 2.8), and RH was 30.0% (SD 7.9). In contrast, in Saskatoon, Saskatchewan, the mean temperature was 20°C and the mean RH was 35% in the winter.\(^22\) The mean indoor CO\(_2\) exceeded generally recommended standards (> 1000 ppm) in 56% (53/95) of the houses (Appendix 3, Supplemental Figure E1, available at www.cmaj.ca/lookup/doi/10.1503/cmaj.202465/tab-related-content).\(^{13,22,32,33}\) Of these, 19 had mean CO\(_2\) values between 1500 and 2500 ppm. The mean concentration of PM\(_{2.5}\) was 17.1 (SD 18.9) μg/m\(^3\), which exceeds World Health Organization 1-year average guidelines for outdoor air of 10 μg/m\(^3\).\(^{3,34,35}\) As mean ambient PM\(_{2.5}\) was 4.93 (SD 1.8) μg/m\(^3\), indoor PM\(_{2.5}\) appeared to be largely a result of indoor sources such as wood stove use, cooking and commercial tobacco use. Concentrations of VOCs were generally acceptable, although the level of m- and p-xylene was elevated.\(^{3,36–38}\)

The mean SAM in the occupied space was 0.2 m\(^2\). However, 9% (9/98) of homes had SAM over 1%–14% of the floor area of the occupied space. Six houses had very high SAM (> 1 m\(^2\)) visible below grade (in crawlspace and basements), which is much greater than reported elsewhere in Canada.\(^{39,40}\) The mean load of settled dust endotoxin was 560 532 (SD 2 264 295) EU/m\(^2\), which is markedly higher than previously reported in southern Canada.\(^{40,41}\) Firewood was stored indoors in most houses, and half (30/60) of these had subjectively “moderate or large” amounts of sawdust. Endotoxin levels did not differ substantially by heating source (Table 2). Levoglucosan levels were relatively low. The mean concentration of dust mite allergens Der p1 and Der f1 were 218.9 (SD 655.8) ng/g and 9.2 (SD 17.9) ng/g, respectively, which were less than that reported in other Canadian houses.\(^{42}\)

Table 2: Indoor air quality in houses visited, \(n = 98\) participants

| Exposure variable | No. (%) of missing variables | Mean ± SD | Median (IQR) |
|-------------------|------------------------------|-----------|--------------|
| Relative humidity in child’s room | 5 (5) | 35.0 ± 9.0 | 33.5 (28.5–43.0) |
| Relative humidity in living room | 3 (3) | 30.0 ± 7.9 | 28.1 (24.0–36.0) |
| Mean living room temperature | 3 (3) | 25.6 ± 2.8 | 25.7 (23.6–27.6) |
| CO\(_2\), ppm | 3 (3) | 1146.0 ± 505.5 | 1078.2 (845.4–1283.9) |
| Max CO\(_2\), ppm | 3 (3) | 1797.1 ± 708.1 | 1691.0 (1377.5–1948.0) |
| Homes with mean CO\(_2\) > 1000, \(n\) (%) | 3 (3) | 53 ± 55.8 | |
| Formaldehyde, μg/m\(^3\) | 2 (2) | 19.9 ± 11.9 | 18.4 (11.4–26.1) |
| Acetaldehyde, μg/m\(^3\) | 2 (2) | 18.0 ± 14.9 | 15.7 (10.2–25.2) |
| Glucans, μg/m\(^2\) | 8 (8) | 272.8 ± 673.7 | 39.6 (14.1–225.3) |
| Endotoxin, EU/m\(^2\) | 8 (8) | 560 532.2 ± 2 264 294.9 | 35 441.4 (12 943.3–144 727.8) |
| Endotoxin levels in \((n = 71\) homes): | | | |
| Homes heated by wood and electricity | 5 (7) | 300 558.8 ± 801 266.3 | 37229.2 (137 967.7–135 025.4) |
| Homes heated by electricity only | 3 (20) | 2 373 263.0 ± 5783 731.1 | 24222.8 (16 806.6–185 652.9) |
| Homes heated by other heating sources | 0 (0) | 177 655.2 ± 294 689.1 | 26 589.7 (12 191.7–186 518.7) |
| Surface area mould, m\(^2\) | 0 (0) | 0.2 ± 0.5 | 0.0 (0.0–0.1) |
| Levoglucosan, μg/m\(^3\) | 15 (15) | 0.1 ± 0.3 | 0.0 (0.0–0.1) |
| PM\(_{2.5}\) (DustTrak), μg/m\(^3\) | 7 (7) | 66.8 ± 85.3 | 40.5 (26.3–74.9) |
| PM\(_{1}\), gravimetric, μg/m\(^2\) | 11 (11) | 17.1 ± 18.9 | 11.7 (6.8–19.2) |
| Ultrafine particulate matter, count/cm\(^3\) | 13 (13) | 31 035.3 ± 19 399.5 | 25 797.0 (16 924.9–38 535.1) |
| Benzene, μg/m\(^3\) | 4 (4) | 2.2 ± 1.8 | 1.6 (0.9–3.1) |
| Toluene, μg/m\(^3\) | 4 (4) | 7.8 ± 10.5 | 3.9 (2.4–8.8) |
| m-xylene + p-xylene concentration, μg/m\(^3\) | 4 (4) | 6.3 ± 18.2 | 2.3 (1.3–5.2) |
| Nicotine + nicotyrine concentration, μg/m\(^3\) | 4 (4) | 0.6 ± 1.4 | 0.0 (0.0–0.5) |

Note: CO\(_2\) = carbon dioxide, IQR = interquartile range, PM\(_{2.5}\) = particulate matter < 2.5 μm, ppm = parts per million, SD = standard deviation.
Respiratory diseases
Lower respiratory tract infections were frequent, with a mean of 0.73 (SD 1.45) LRTIs per year of life. Of participants, 21% (20/97) were admitted to hospital in the first 2 years of life and 25% (24/98) were medically evacuated for a respiratory illness. Children were seen in the health centre with URTIs an average of 1.6 (SD 1.8) times per year of life. Wheezing with colds occurred in more than one-third (39%, 38/98), but only 4/98 of children (4%) received a diagnosis of asthma.

Table 3: Major housing issues identified by the indoor air quality specialist

| Type of issue                      | No. (%) of houses affected n = 98 | Description                                                                 |
|-----------------------------------|-----------------------------------|-----------------------------------------------------------------------------|
| Immediate safety                  |                                   |                                                                             |
| 1 (1)                             |                                   | No wood stove chimney shield (extreme fire hazard)                           |
| 1 (1)                             |                                   | No insulation baffle around chimney in attic: fire hazard                    |
| 2 (2)                             |                                   | Electrical fire or shock hazard                                             |
| 1 (1)                             |                                   | House shifted; many large gaps with rotten wood                            |
| 1 (1)                             |                                   | Possible cracked heat exchanger in wood stove; house contaminated with soot and carbon monoxide risk if furnace blower turned off |
| Water penetration (and plumbing)  |                                   |                                                                             |
| 13 (13)                           |                                   | Plumbing fixture leaks with area dampness (bathroom, kitchen, water tank)    |
| 13 (13)                           |                                   | Mouldy or damp crawlspace floor (in most cases, polyurethane sheet vapour barrier over dirt floor missing) |
| 10 (10)                           |                                   | Sump pump not working, not present or drains too close to foundation         |
| 4 (4)                             |                                   | Sump pump discharge pipe not connected                                     |
| 6 (6)                             |                                   | Roof leaks with mould or damage to ceilings, walls                         |
| 4 (4)                             |                                   | Exterior damage leading to water penetration                                |
| 3 (3)                             |                                   | Broken chimney flashing — chimney leaks when it rains                       |
| 3 (3)                             |                                   | Plumbing not working                                                       |
| Air quality or ventilation        |                                   |                                                                             |
| 2 (2)                             |                                   | Exhaust fans vent into attic                                                |
| 1 (1)                             |                                   | Heat recovery ventilator fresh air intake near oil furnace exhaust          |
| 1 (1)                             |                                   | No openable windows, no exhaust fans and no heat recovery ventilator        |
| 1 (1)                             |                                   | Oil furnace back drafting                                                  |
| 1 (1)                             |                                   | Wood stove back drafting                                                   |

Multivariable modelling for primary outcome of lower respiratory tract infection
In a multivariable model with complete cases, there was evidence of an association between log endotoxin and the rate of LRTIs that approached conventional statistical significance (adjusted rate ratio [RR] 1.14 per unit of log [EU/m²], 95% confidence interval [CI] 0.98–1.33), and age and the rate of LRTIs (adjusted RR 0.65 per year of life, 95% CI 0.46–0.91) (Table 4). Results were similar using the imputed data set (Appendix 2, Supplementary Table S2).

Multivariable modelling for secondary respiratory outcomes (upper respiratory tract infections and wheeze with a cold)
In a multivariable model using complete cases, there was evidence for an association between SAM > 0.2 m² and rates of URTI that approached conventional statistical significance (adjusted RR 1.61, 95% CI 0.95–2.72), as well as age and rate of URTI (adjusted RR 0.79 per year of life, 95% CI 0.65–0.98) (Table 5 and Appendix 2, Supplementary Table S3). In a multivariable model of complete cases with wheeze with colds as the outcome, log endotoxin was associated with wheeze with colds (odds ratio [OR] 1.32 per unit of log [EU/m²], 95% CI 1.04–1.70) and with age (OR 1.70 per year, 95% CI 1.03–2.90) (Table 6). These effects were slightly attenuated using imputed data in the model (Appendix 2, Supplementary Table S4).

Interpretation
This quantitative assessment confirmed previous surveys that reported that many FN homes require major repair(s).5 The housing crisis experienced by FN people in Canada is historically well documented.4,34,44 Centuries of assimilation tactics, colonialism and systemic racism have created structural barriers including employment, education, economic and housing inadequacies, as well as systematically disrupting transfer of intergenerational life skills. Inequalities and underfunding have resulted in houses that are poorly constructed and of insufficient size, with inadequate funding for maintenance and upkeep. With the loss of integrity of the air and vapour barrier, overcrowding, inadequate ventilation and indoor storage of firewood, contamination with mould and endotoxin was common, with high interior SAM and extraordinarily elevated endotoxin loading. Endotoxin exposure was associated with wheeze with colds and tended to be associated with LRTI, whereas SAM tended to be associated with URTI visits.

Endotoxin is a cell wall component of gram-negative bacteria.45,46 The mean load of settled dust endotoxin in study homes was much higher than in American homes in general (17600 EU/m²).23 Settled dust endotoxin has previously been associated with wheezing in young children,47,48 and airborne endotoxin with acute respiratory illnesses and infections in infants.49 Endotoxin has complex effects on immune function, with early exposure reducing the incidence of asthma, and late exposure increasing the risk of exacerbations in people with pre-existing asthma.46,47 The high prevalence of wheeze with colds suggests asthma may be underdiagnosed, although the term “wheezing” may have been used...
### Table 4: Multivariable modelling for LRTI (complete case analysis, n = 81, with 74 LRTI visits)*

| Covariate                              | Unadjusted rate ratio (95% CI) | Adjusted rate ratio (95% CI) |
|----------------------------------------|--------------------------------|------------------------------|
| Age, yr                                | 0.62 (0.45–0.86)               | 0.65 (0.46–0.91)             |
| Born premature, yes                    | 1.68 (0.73–3.98)               | 1.57 (0.76–3.24)             |
| PM$_{2.5}$, µg/m³                      | 0.999 (0.994–1.005)            | 1.00 (0.99–1.00)             |
| Surface area mould > 0.2 m², yes       | 0.33 (0.10–0.99)               | 0.44 (0.14–1.20)             |
| Log endotoxin, EU/m²                   | 1.14 (0.96–1.36)               | 1.14 (0.98–1.33)             |

CO$_2$ (3-knot restricted cubic spline†), ppm
- First coefficient 1.003 (1.000–1.005) 1.001 (0.999–1.003)
- Second coefficient 0.996 (0.992–0.999) 0.998 (0.994–1.001)

Note: CI = confidence interval, CO$_2$ = carbon dioxide, LRTI = lower respiratory tract infection, PM$_{2.5}$ = particulate matter < 2.5 µm, ppm = parts per million.
*Rate ratios represent estimated ratio of events/year of life between groups. Rate ratios are per-unit increase for continuous variables or for the described group (e.g., surface area > 0.2 m² or born premature) compared with the referent. An adjusted rate ratio > 1 indicates the covariate is associated with increased event rates.
†Knots for CO$_2$: 600.1, 1054.2, 1865.1.

### Table 5: Multivariable modelling for URTI (complete case analysis, n = 81, with 189 URTI visits)*

| Covariate                              | Unadjusted rate ratio (95% CI) | Adjusted rate ratio (95% CI) |
|----------------------------------------|--------------------------------|------------------------------|
| Age, yr                                | 0.79 (0.64–0.97)               | 0.79 (0.65–0.98)             |
| Born premature, yes                    | 0.93 (0.55–1.58)               | 0.89 (0.53–1.48)             |
| PM$_{2.5}$, µg/m³                      | 1.001 (0.997–1.004)            | 1.000 (0.997–1.003)          |
| Surface area mould > 0.2 m², yes       | 1.65 (0.96–2.88)               | 1.61 (0.95–2.72)             |
| Log endotoxin, EU/m²                   | 1.000 (1.000–1.001)            | 1.000 (1.000–1.001)          |

CO$_2$ (3-knot restricted cubic spline†), ppm
- First coefficient 1.28 (0.96–1.72) 1.21 (0.90–1.64)
- Second coefficient 0.73 (0.51–1.03) 0.78 (0.54–1.11)

Note: CI = confidence interval, CO$_2$ = carbon dioxide, PM$_{2.5}$ = particulate matter < 2.5 µm. URTI = upper respiratory tract infection.
*Rate ratios represent estimated ratio of events/year of life between groups. Rate ratios are per-unit increase for continuous variables or for the described group (e.g., surface area > 0.2 m² or born premature) compared with the referent. An adjusted rate ratio > 1 indicates the covariate is associated with increased event rates.
†Knots for log endotoxin: 7.95, 10.50, 14.71.

### Table 6: Multivariable modelling for wheeze with cold (complete case analysis, n = 81, with 31 participants reporting wheeze with cold)*

| Covariate                              | Unadjusted odds ratio (95% CI) | Adjusted odds ratio (95% CI) |
|----------------------------------------|--------------------------------|------------------------------|
| Age, yr                                | 1.75 (1.10–2.86)               | 1.70 (1.03–2.90)             |
| Born premature, yes                    | 1.33 (0.43–4.03)               | 1.09 (0.32–3.62)             |
| PM$_{2.5}$, µg/m³                      | 0.997 (0.997–1.003)            | 0.998 (0.989–1.004)          |
| Surface area mould > 0.2 m², yes       | 1.01 (0.28–3.36)               | 0.82 (0.20–3.02)             |
| CO$_2$, ppm                            | 1.000 (0.999–1.001)            | 1.000 (0.998–1.001)          |
| Log endotoxin, EU/m²                   | 1.33 (1.06–1.72)               | 1.32 (1.04–1.70)             |

Note: CI = confidence interval, CO$_2$ = carbon dioxide, PM$_{2.5}$ = particulate matter < 2.5 µm.
*Odds ratios are per-unit increase for continuous variables or for the described group (e.g., surface area > 0.2 m² or born premature) compared with the referent.
imprecisely. Endotoxin levels were likely increased by indoor storage and use of firewood and accumulation of sawdust.

Many houses were poorly situated, leaving them prone to flooding and water penetration. Wet and mouldy crawlspaces were common. Mean 1,3-β-D-glucan loading in study houses was much higher than in infants’ houses in Cincinnati (18.4 μg/m²). Surface area of visible mould tended to be associated with URTIs, which may be clinically important as URTIs are important antecedents for more severe respiratory illnesses, including LRTI and asthma exacerbations. Surface area of visible mould above 0.2 m² has more severe respiratory illnesses, including LRTI and asthma exacerbations. Mean indoor CO₂, as a proxy for indoor burden of dust mite antigen, but less than 15% had an operational one. Similarly, 57.8%–87.5% of FN houses in northern Manitoba had no or a nonfunctional HRV. The lack of substantial associations between CO₂ or other IEQ factors and LRTI may reflect a lower risk of LRTI than that observed in Inuit children and children in low-income countries. Indoor PMₓ.₅ concentrations in our study were not unusual for homes heated by woodstoves. Levoglucosan is primarily a marker of wood combustion. The indoor levoglucosan/PMₓ.₅ ratio of 0.13% (SD 0.31) was less in rural British Columbia (1.0%), suggesting a higher contribution of commercial tobacco smoke. Commercial tobacco smoke exposure is a known risk factor for LRTI, but the lack of unexposed children precluded meaningful analysis. Elevated indoor concentrations of PMₓ.₅ have been associated with LRTI elsewhere. Some IEQ problems might be rectified by residents with relevant educational tools related to HRV use, firewood storage and furniture placement to promote air circulation, and reduce moisture accumulation and mould growth. Often, this will require addressing systemic, structural and economic barriers faced by residents.

Our study had the benefit of engaging an indoor air quality specialist, who used standardized tools and quantitative methods. We had broad community support and obtained direction from the SLFNHA Chief’s Committee on Health. Given our preliminary results, we supported capacity building by working with FN students to develop educational deliverables and by developing HRV educational programs for housing departments.

Limitations

Our study had limitations common to most studies of IEQ: the cross-sectional design and disparity between the time of IEQ measurements and historical outcomes means that only associations, rather than causality, can be surmised. Precision and power were limited owing to the small sample size. The larger proportion of eligible children who were included, compared with typical urban research, enhanced generalizability, although lack of random sampling increased the risk of selection bias. Because we assessed several exposures and outcomes, there may be an increased risk of type I errors. Flooring settled dust mite is often used as a proxy for indoor burden of dust mite antigen, but less dust could be collected as most houses were not carpeted. We therefore also sometimes collected dust from upholstered furniture, which has been done elsewhere, but is less well standardized. The 2 methods for quantifying PMₓ.₅ — gravimetric and photometric — are not completely comparable, limiting comparison with other studies. Variable quantification methods for endotoxin also hampers comparison between studies. Further research is needed to determine how best to use levoglucosan as a marker of indoor wood combustion. The best method of quantifying indoor mould is controversial, particularly in houses where much of the mould is located outside the lived space, such as crawlspaces, but from where it can potentially infiltrate. We did not record how many households were approached for the study but declined participation, although we believe we have a close estimate of the number of households that declined.

Conclusion

Many houses in these FN communities had substantial IEQ problems. Presence of endotoxin was associated with wheezing with colds and tended to be associated with LRTI in young children. Surface area of visible mould tended to be associated with URTI visits. Urgent collective action is needed to respond to historically damaging impacts of colonization, including systemic indifference. Increased housing stock appropriate for local geographic, climatic and cultural needs should be matched to solutions that are FN led and governed. Economic opportunity, elimination of food insecurity and provision of portable water will allow communities and residents to apply more resources to the upkeep of existing houses. Such measures will improve the overall health of FN peoples, particularly vulnerable family members, such as children and elders.

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**Competing interests:** Thomas Kovesi reports being a member of the board of governors of the Ontario Lung Association. Dr. Kovesi also reports using equipment from Health Canada for this study, and that sample analysis and data compilation were performed by Health Canada and Environment Canada. Yoko Schreiber reports receiving fees from the Indigenous Services Canada—First Nations and Inuit Health Branch Pharmacy and Therapeutics Committee, and acting as chair of the Indigenous Health Committee, Association of Medical Microbiology and Infectious Diseases Canada (unpaid position). Gail Lawlor reports receiving payment from the study operating grant for time spent in the homes conducting the surveys and setting up the IAQ Testing, as well as reimbursement from the study operating grant for expenses incurred for travel and accommodation in the four First Nations communities. No other competing interests were declared.

This article has been peer reviewed.

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**Contributors:** Thomas Kovesi and Gary Mallach contributed to the conception and design of the work; the acquisition, analysis and interpretation of the data; and drafting of the manuscript. Yoko Schreiber and Ryan Kulka contributed to the conception and design of the work, the acquisition of data, and drafting of the manuscript. Michael McKay contributed to the design and interpretation of the work and drafting the manuscript. Gail Lawlor and Len Kelly contributed to the design and interpretation of the work, acquisition of data, and drafting of the manuscript. Nick Barrowman and Anne Tsampalieros contributed to the analysis and interpretation of the work and drafting of the manuscript. Ariel Root contributed to the conception and design of the work and drafting of the manuscript. Michael Kirlew contributed to the conception and design of the work. J. Miller contributed to the conception and design of the work; the analysis and interpretation of the data; and drafting of the manuscript. All of the authors revised the manuscript critically for important intellectual content, gave final approval of the version to be published and agreed to be accountable for all aspects of the work.

**Funding:** Indigenous Services Canada, Health Canada; Children’s Hospital of Eastern Ontario Research Institute.

**Data sharing:** This data set is not available for sharing. When participants consented to participating in the study, they did not consent to data beyond the research team. Readers are welcome to contact the corresponding author for further clarification.

**Acknowledgements:** The authors thank Janet Gordon and the Sioux Lookout First Nations Health Authority, Nishnawbe Aski Nation, and the communities, Band Councils and Health Centres of Lac Seul First Nation, Kasabonika Lake First Nation, Sandy Lake First Nation, and Kitchenuhmaykoosib Inninuwig First Nation for their advice and support. The authors thank the Chiefs and members of each community: Chief Derek Maud (Lac Seul), Chief Eno H. Anderson (Kasabonika), Chief Delores Kakegamic (Sandy Lake), Chief Donny Morris (Kitchenuhmaykoosib Inninuwig); Sol Mamawka, Member of Provincial Parliament (Riding of Kiiwetinoong, Legislative Assembly of Ontario); Bruce Fraser (Hazard Identification Division, Health Canada); and Constantine Tikhonov (Indigenous Services Canada) for their wisdom and support. The authors acknowledge the kind support of Ewa Babek-Zlotorzynska (Analysis and Quality Section, Air Quality Research Division, Atmospheric Science and Technology Directorate, Science and Technology Branch, Environment Canada). The authors recognize Tim Shin (Air Pollution Exposure Science Section, Health Canada) for assistance with compiling the exposure data set. Finally, the authors thank the Community Health Representatives and families who participated in this study. Written permission to identify the study communities in publications was provided by the Chief of each community.

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**Accepted:** Dec. 10, 2021

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