CHARACTERIZING THE INDOOR AIR ENVIRONMENT IN THE HOMES OF FIRST NATION CHILDREN AND YOUTH USING REMOTE COMMUNITY-BASED RESEARCH METHODS: HOUSEHOLD CONDITIONS, AIR QUALITY, AND PRELIMINARY HEALTH OUTCOMES

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ABSTRACT

Indoor air quality is a critical determinant of physical and mental health. Despite evidence linking poor indoor air quality to adverse health outcomes, this issue is understudied in the context of First Nations children and youth health and wellbeing. The objectives of this study were to (1) characterize indoor air quality, housing conditions, and respiratory health of children living in the Kanesatake First Nation and (2) evaluate the feasibility of using remote community-based participatory methods in the context of First Nations health research. Community-assisted data collection occurred between June 2021 and February 2022 in the Kanesatake First Nation, Quebec. Indoor air data were collected from 31 randomly selected houses. Results showed elevated levels of contaminants, including particulate matter, benzene, toluene, and xylene, compared to the Canadian averages. Houses generally lacked adequate ventilation, and over one-quarter were reported to be in need of major repairs. We developed instruction tools for air sampling and house inspection to facilitate off-site data collection. High rates of participant completion (95%) and low attrition rates (5%) indicated the feasibility of remote community-based participatory research methods. Lessons learnt are summarized and important recommendations are made for adaptation to improve future data collection. This research served as a pilot project for a multi-year, cross-Nation study, as well as the first study to evaluate the indoor air environment in the Kanesatake First Nation.

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LIST OF ABBREVIATIONS

AQ Egg	Air Quality Egg (AQ Egg Model: 2018)
AFN	Assembly of First Nations
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CBPR	Community-based participatory research
CHMS	Canada Health Measures Survey
CMHC	Canada Mortgage and Housing Corporation
CIRNAC	Crown-Indigenous Relations and Northern Affairs Canada
COPD	Chronic Obstructive Pulmonary Disease
CO_2	Carbon Dioxide
CR	Community Researcher
D4	Octamethylcyclotetrasiloxane
D5	Decamethylcyclopentasiloxane
DF	Detection Frequency
DNA	Deoxyribonucleic Acid
ECCC	Environment and Climate Change Canada
EPA	Environmental Protection Agency
FEHNCY	Food, Environment, Health and Nutrition of First Nations Children & Youth
FEV1	Forced Expiratory Volume in one second
FN	First Nations
FNIAS	First Nations Indoor Air Study
FNIGC	First Nations Information Governance Centre
FNRHS	First Nations Regional Health Survey
FVC	Forced Vital Capacity
GC/MS	Gas chromatography/mass spectrometry
HRV	Heat Recovery Ventilator
IAE	Indoor air environment
IAP	Indoor air pollutants
IAQ	Indoor air quality
IARC	International Agency for Research on Cancer

IHP	Indigenous Health Promotion
I/O	Indoor/Outdoor ratio
LOD	Limit of Detection
LRTI	Lower respiratory tract infection
MEF 25-75	Maximum Expiratory Flow 25-75% of Exhalation
NIST	National Institute for Standards in Technology
OAQ	Outdoor air quality
OCAP®	Ownership, Control, Access, and Possession
PM	Particulate Matter
$PM_{1.0}$	Particulate matter (aerodynamic diameter of 1.0µm or less)
$PM_{2.5.}$	Particulate matter (aerodynamic diameter of 2.5µm or less)
PM_{10}	Particulate matter (aerodynamic diameter of 10µm or less)
ppm	Parts per million
RPD	Relative Percent Differences
RSV	Respiratory syncytial virus
SAS	Statistical Analysis Software
SES	Socioeconomic Status
SOP	Standard Operating Procedures
UNBC	University of Northern British Columbia
VOC	Volatile organic compounds
WHO	World Health Organization

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CHAPTER 1 | INTRODUCTION

INDOOR AIR QUALITY AND HUMAN HEALTH

Indoor Air Quality (IAQ) is widely considered an important determinant of health in Canada and worldwide. The Environmental Protection Agency (EPA) defines IAQ as the air quality inside and surrounding buildings, particularly concerning the health, well-being, and comfort of building occupants (EPA 2021). Exposure to household air pollutants is associated with over 4 million premature deaths per year on a global scale and has been identified by the World Health Organization (WHO) as one of the most important environmental risk factors for disease (WHO 2010). The indoor air environment (IAE) is shaped by a mixture of pollutants originating from both indoor and outdoor sources and may include various chemical and biological contaminants. The air pollutants of major health concern are numerous in their identities and sources, and include small particulate matters (PMs), volatile organic compounds (VOCs), carbon monoxide, aerosols, and various biological contaminants originating from mould and pet dander. These contaminants have been studied extensively as contributors to cardiorespiratory morbidity, and the association between poor IAQ and respiratory illness is well-established in adults. Adverse health outcomes linked to poor IAQ include pneumonia, asthma exacerbation, and other acute respiratory tract infections (Adaji et al., 2018, Croft et al., 2019, Karakatsani et al., 2014). Moreover, chronic exposure to poor IAQ has been associated with chronic disease outcomes such as cancers, diabetes, and chronic obstructive cardiopulmonary illnesses (COPD) (Hoffman et al., 2012, Ko et al., 2012, Mishra et al., 2020). These effects are particularly pronounced in populations occupationally exposed to high levels of key contaminants over long periods of time (Lawin et al., 2018, Torén et al., 2007). In the Canadian context, it has been found that adverse health outcomes linked to indoor air pollution exposure are particularly pronounced in groups with pre-existing, underlying comorbidities (To et al., 2020).

While cancers and cardiovascular illnesses associated with poor indoor air quality are more commonly seen in adults, acute respiratory outcomes tend to be more prevalent in younger populations. Indeed, the global burden of IAQ-related disease has been shown to fall disproportionately on children, as well as on elderly people and women (WHO, 2013). Children are more susceptible to the adverse health effects of chronic exposure to indoor air contaminants as the pulmonary system does not completely develop until the late adolescent years. Children are also known to inhale higher volumes of air and its constituents per unit of body mass and possess higher minute ventilation compared to adults (Bateson, 2008). Several epidemiological studies have reported associations between exposure to key indoor air pollutants and respiratory morbidity in younger populations (Darrow et al., 2014, Breysse et al., 2010, Gordon et al., 2014). Exacerbation of asthma, lower respiratory tract infections (LRTI), and respiratory syncytial virus (RSV) are common outcomes found in children exposed to poor IAQ (Vandini et al., 2013, Vanker et al., 2017). Respiratory issues experienced during childhood can increase one's risk for respiratory illness in the adult years, and symptoms may persist for several years. Therefore, the study of IAQ and pediatric health is important in preventative research.

Disparities in socioeconomic status, housing adequacy, and access to interventions for improving indoor air quality are common moderators of the relationship between indoor air quality and respiratory health (Brown et al., 2011). Environmental pollution tends to have the greatest impact on vulnerable communities within society due to both differential access to preventive resources and a higher incidence of underlying health conditions (Milojevic et al., 2017). Housing conditions such as ventilation adequacy, airtightness, ability to open windows, and dampness are important considerations for maintaining IAQ, and poor household conditions are experienced disproportionately among populations living in lower socioeconomic status (SES) conditions (Ferguson et al., 2022). In Canada, studies have shown that members of the general population spend approximately 88% of their time indoors (Health Canada, 2018) and maintaining adequate IAQ is thus a critical public health consideration.

The Indigenous peoples of what is now Canada are historically and culturally diverse. The term Métis refers to a collective of cultural and ethnic identities that resulted from the union of Indigenous people and European settlers. Indigenous peoples of the Arctic and far North are collectively known as the Inuit. First Nations are defined as original peoples of Canada who are ethnically neither Métis nor Inuit. According to the 2016 Census, there were 634 First Nations communities across the country, with a total population of 977, 230 (Statistics Canada, 2016). First Nation (FN) reserves generally have small populations; 70% of communities have populations of less than 500 living on reserve and 4% have over 2000 inhabitants. First Nations are both the youngest and fastest-growing populations in Canada. According to the 2016 Census, approximately one third (29.9%) of First Nations were aged 14 or younger (Statistics Canada, 2016). Health disparities affecting First Nations are well-documented, with younger populations bearing an increased burden of disease compared to similar age groups in the general population. First Nations children and youth are more likely to face health issues such as diabetes, anemia, waterborne and infectious diseases, disabilities, and respiratory health problems. Indeed, the Regional Health Survey found that one third of First Nations children had been diagnosed with a health condition (First Nations Health Authority, 2019). The strong socioeconomic gradient shaping First Nations health stems from a legacy of historical violence, forced assimilation, and displacement of First Nations populations to remote communities lacking in resources. Housing conditions in First Nations communities have been chronically inadequate and have been identified as exacerbators of health disparities. A review of children's respiratory health and housing conditions as they pertain to specific indoor air contaminants is described hereafter.

OVERVIEW OF IAQ AND FIRST NATION CHILDREN'S HEALTH

Despite the health risks associated with exposure to indoor air pollutants (IAPs), specifically to children, the characterization of IAQ in First Nation (FN) communities in Canada has not been adequately addressed. This is a problematic knowledge gap, particularly given the small number of studies that have shown IAPs to be higher in Indigenous households than those measured in the general population (Kovesi et al., 2022, Lawrence and Martin, 2001, Weichenthal et al., 2013). Children's respiratory health has been established as a significant concern in FN populations, with FN communities reporting elevated rates of pediatric hospitalizations for respiratory-related distress compared to the general population (Jouvet et al., 2010, He et al., 2017). Indeed, infectious diseases and diseases of the respiratory system were the leading cause of infant hospitalization in FN and Inuit children in a retrospective cohort study conducted in Quebec (He et al., 2017). A recent study conducted by Kovesi et al. (2022) found a high incidence of both childhood wheezing with colds and infant hospitalization for LRTI in populations living in the Sioux Lookout FN Health Authority region. The concerning trends in adverse respiratory health in FN and Inuit communities may in part be attributable to inadequate and unsuitable housing conditions such as overcrowding. Overcrowded homes are defined as households in which the number of occupants exceeds the available dwelling space, as measured in bedrooms, living areas, or floor space, possibly resulting in adverse mental or physical health outcomes (WHO, 2018). In 2017, a census report showed that 19% of FN households needed major repairs, with 18% of families residing in overcrowded homes (Statistics Canada, 2017). Similar findings have been reported in further studies and assessments (Larcombe et al., 2012, Carrière et al., 2017). Inadequate housing has been known to exacerbate children's negative physical and mental health outcomes (Weitzman et al., 2013), with respiratory health issues being a demonstrated housing-related health outcome in FN children (Crighton et al., 2010, Berghout et al., 2005). Poor ventilation, overcrowding, moisture damage, and inadequate temperature regulation systems are associated with increased exposure to key IAPs. The lack of generalizable knowledge available on the levels and predictors of indoor air pollution in FN households presents major barriers to community decision-making around these issues. Although FN communities possess a breadth of knowledge on health and wellness, the enduring impacts of colonialism and land dispossession have produced socio-environmental conditions that threaten the air quality and health of FN children and youth (Reading, 2015).

PARTICULATE MATTER AND FIRST NATION CHILDREN'S HEALTH

Fine particulate is considered to be among the most harmful air contaminants when considering cumulative, lifelong health impacts (WHO, 2022). Fine particulates are complex droplet mixtures whose constituents vary in size, density, shape, and chemical composition. They are defined broadly as particles with a mean aerodynamic diameter of 10μm and less, and can be split into various size fractions. Particulate matter (PM) with a mean aerodynamic diameter of 2.5μm and less ($PM_{2.5}$) originates primarily from combustion sources such as coal burning and vehicle emissions, and can also contain constituents such as mould spores and endotoxins. Due to its small size, $PM_{2.5}$ can penetrate the lower airways and deposit in the alveoli, where it can cross the alveolar membrane and enter the pulmonary and systemic circulations. Animal and human studies have demonstrated an association between $PM_{2.5}$ exposure and inflammatory injury; metal, organic, and free radical components of $PM_{2.5}$ are of particular concern as known mediators of oxidative damage in epithelial tissue (Xing et al., 2016). Chronic exposure to $PM_{2.5}$ is strongly linked to cardiovascular illness, while acute rises in concentration exposure can exacerbate pre-existing conditions, such as asthma and coronary heart disease (Madrigano et al., 2013, Liang et al., 2014, Wang et al., 2022).

As aforementioned, indoor PM levels are influenced by several environmental and behavioural factors. Presence of smoking occupants in the home is strongly associated with PM levels indoors. In studies conducted by Health Canada in different Canadian cities, the average $PM_{2.5}$ concentrations were less than 15µg/m^3 in non-smoking homes, and less than 35µg/m^3 in smoking homes (Health Canada, 2012). A recent study by Mendell et al. (2022) found that households in low socioeconomic status (SES) neighbourhoods in Toronto had median $PM_{2.5}$ values twice as high as comparable single-family homes in higher SES neighbourhoods; this factor rose to three times as high in smoking apartments in the low SES cohort. Smoking is highly prevalent in First Nations populations, with 33% of First Nations between the ages of 13-44 reporting smoking on a regular basis (Statistics Canada, 2012). In 2022, Kovesi et al. found that indoor $PM_{2.5}$ levels in the Sioux Lookout FN Health Authority region were related to tobacco use, the presence of a woodstove, and cooking. Other common PM predictors include the use of a fireplace, storage of firewood indoors, and presence of pets indoors. PM is a non-threshold contaminant, meaning there is no concentration at which the adverse health effects of exposure to PM are negligible. Health Canada, therefore, has no guideline level for PM but recommends that indoor levels be kept as low as possible (Health Canada, 2012). The WHO's guidelines for outdoor PM exposure are thus sometimes used to contextualize indoor PM findings. The WHO recommends an annual $PM_{2.5}$ exposure limit 5µg/m^3, and a 24-hour limit of 15µg/m^3. For PM_{10}, the recommended exposure limit is 15µg/m^3 annually and 45µg/m^3 over a 24-hour period (WHO, 2021).

VOCs AND FIRST NATION CHILDREN'S HEALTH

Volatile Organic Compounds (VOCs) are a broad class of chemicals found in indoor air. VOCs are defined by the WHO as chemicals with boiling points lower than 250°C, low solubility in water, and sufficiently elevated vapour pressure to partition primarily to the gas state. While some VOCs are naturally occurring, most VOCs found in indoor air environments originate from anthropogenic sources and are used commonly in manufacturing processes. In the household environment, VOCs are typically found in industrial solvents, paints, thinners, candles, varnishes, and flame retardants. VOCs such as Benzene, Toluene, Ethylbenzene, and Xylenes (also known as the BTEX group), are of particular concern due to their frequent detection in indoor environments. BTEX compounds typically originate from fuel and cooking sources and are also common constituents of cigarettes.

The primary route of exposure for VOCs is through inhalation of indoor air. Several VOCs are classified as known or possible carcinogens, toxicants, or irritants and are associated with cancers of the lung and cardiorespiratory system. For example, benzene, 1,3-butadiene, and vinyl chloride, are Group 1 carcinogens as classified by the International Agency for Research on Cancer (IARC) (IARC, 2008, 2018). While VOCs can affect different metabolic pathways through different mechanisms of toxicity, the pathophysiology of several VOCs has been well characterized. For instance, upon entry into the body through inhalation, benzene is metabolized by the liver and lungs, and reactive metabolites are thought to be involved in inducing oxidative stress and DNA damage in the cardiovascular system (McHale et al., 2012). Formaldehyde, another VOC carcinogen, is known to interact with deoxyribonucleic acid (DNA) to produce DNA-adducts that promote cytotoxicity and cell proliferation (National Research Council, 2011). The negative health impacts of occupational exposure to several VOCs are also well-characterized. Occupational exposure to benzene has been studied most extensively, and chronic exposure in the work setting has been associated with the development of lymphoma and leukemias (Zhang et al., 2007, Khalade et al., 2010). Studies have also found that simultaneous occupational exposure to BTEX compounds is associated with acute headaches, fatigue, and airway irritation, specifically amidst workers at gasoline plants and fueling sites (Al-Harbi et al., 2020). A growing body of research has also suggested that exposure to VOCs in the residential environment can lead to a variety of adverse health outcomes, specifically in pediatric populations (Chin et al., 2014, Delfino et al., 2003, Rumchev et al., 2004). For example, several studies have shown that exposure to VOCs in residential and school settings increases the risk of allergy exacerbation and asthma diagnosis in North America and Europe (Rumchev et al., 2004, Saif et al., 2021). In Canada, the Canada Health Measures Survey (CHMS) recently characterized VOC levels in households across the country. However, the CHMS did not include Indigenous (FN, Métis, or Inuit) households. Although there is little existing knowledge on VOC levels in the homes of FN children and youth, a few studies involving Métis and Inuit communities have suggested that higher VOC levels are associated with short-term health outcomes such as allergy and asthma exacerbation in this group. In 2018, Singleton et al. found that higher levels of indoor BTEX were associated with a higher risk of parent-reported wheeze between colds and asthma diagnosis in Alaska Native children. More recently, a study conducted in Nunavik showed elevated levels of benzene and toluene metabolites in Inuit populations compared to the general Canadian population (Caron-Beaudoin et al., 2022). These trends are concerning and support the need to understand VOC sources and exposures in FN, Métis, and Inuit children and youth such that risk reduction measures can be taken.

VENTILATION, TEMPERATURE, AND RELATIVE HUMIDITY

Ventilation is the process through which fresh air is introduced into a building. Adequate household ventilation ensures access to fresh outdoor air, and poor ventilation is often associated with poor IAQ. Ventilation may be estimated by monitoring indoor concentrations of carbon dioxide (CO_2), as humans are the main source of CO_2. High CO_2 levels in the home, as a surrogate for inadequate ventilation and/or overcrowding, have been associated with high rates of respiratory infection in Inuit children (Kovesi et al., 2007), and in the same study, CO_2 levels exceeded the recommended standard (1000 parts per million (ppm)) in 56% of households. Relative humidity is defined as the percentage of water vapour in the room air compared to the percentage vapour in the room at a given temperature. Health Canada recommends an ideal relative humidity range of 30-55% to maintain a comfortable indoor environment. High levels of moisture in indoor air can create environments conducive to the growth and transmission of biological contaminants such as dust mites, moulds, mildews, and bacterial species. Children living in households prone to mould growth are at greater risk of contracting respiratory infections, and higher levels of dust mites increase the risk of asthma. While there is very little existing knowledge on relative humidity and First Nations households, humidity and mould may be a concern in First Nations prone to flooding and/or located near a body of water.

FIRST NATIONS COMMUNITIES AND COMMUNITY-BASED PARTICIPATORY RESEARCH FOR HEALTH RESEARCH

Community-based participatory research (CBPR) is a framework that actively integrates community leadership, voices, and participation into the research process. CBPR is a common and recommended practice for conducting work with Indigenous communities both in Canada and around the world, where a legacy of exploitative research has led to a culture of mistrust between communities and researchers (Schnarch, 2004). CBPR promotes integrated, collaborative partnerships that centre communities as leaders and key stakeholders in the design and execution of a research project. Within the CBPR framework, communities hold decision-making power within the research process, and integrated knowledge translation is prioritized as a collective objective. Moreover, the CBPR framework is solution-oriented, and advocates for research that both aligns with community needs and encourages direct policy and programming initiatives for improving health (Dadich et al., 2019). Particularly in Canada, where the determinants of Indigenous health have and continue to be shaped by policies of assimilation and ongoing colonial oppression (MacDonald & Steenbeek, 2015), CBPR plays an essential role in protecting communities' autonomy and agency in knowledge-gathering processes related to health. It is widely acknowledged that contemporary standards and protocols for conducting research have evolved from a colonial tradition that centres Westernized methodologies and perspectives (Simonds & Christopher, 2013). In 1998, the First Nations Information Governance Centre (FNIGC) developed the principles of Ownership, Control, Access, and Possession (OCAP®) to protect and promote the sovereignty of Indigenous peoples involved in research. The framework was initially developed to guide the implementation of the First Nations Regional Health Survey (FNRHS) and is now a common practice used for building and negotiating relationships between First Nations communities and researchers (FNIGC, 2014). The Principles of OCAP® assert that First Nations have full ownership over all data collected within their community and have the power to control access to and physical possession of these data, as well as how these data are used. In more specific terms, the Principles of OCAP® are outlined as:

- ***Ownership***: It is the collective right of the community to own all information and data collected within the community, and by extension, each community member owns their personal data.
- ***Control***: The community reserves the right to control all aspects of research conducted, including research processes and data and resource management.
- ***Access:*** First Nations are within their rights to access and control all information and data collected within their communities at any time, regardless of where this information is being stored or held.
- ***Possession:*** First Nations control the physical storage of data, including the location in which the data are stored and how these data may be accessed.

Both the Principles of OCAP® and CBPR are powerful frameworks for conducting collaborative research with Indigenous communities. Several projects have been undertaken by First Nations and partnering research bodies in recent years to understand and address determinants of health in ways that prioritize Indigenous sovereignty and cultural history (Chan et al., 2021, Petrucka et al., 2012, Naqshbandi et al. 2011, Ritchie et al. 2013, Funnell et al. 2020) .

In environmental research, CBPR is growing in popularity as a powerful approach to collecting air quality data worldwide. CBPR offers a unique framework for effecting meaningful, community-focused improvements in IAQ through research, as it promotes a heightened awareness of underlying, at times community-specific determinants of poor IAQ (Commodore et al., 2017). Moreover, the increasing availability of low-cost, accessible air quality monitoring equipment is leading to rapidly evolving methods for air quality monitoring across populations. In Canada, the Assembly of First Nations (AFN) considers air pollution a major and widespread concern for First Nations living both on reserve and in urban environments (AFN, 2018). Due to long-range environmental transport, FN communities in the North are affected by air pollutants transported from urban and industrial areas where air pollution is typically higher (Selin & Selin, 2008). As such, FN leadership has advocated for air pollution as an important area for gathering more knowledge (AFN, 2018). While knowledge about air pollution and its effects on Indigenous communities, particularly children, is greatly lacking, CBPR has been used in the past to begin exploring these questions. In 2013, the First Nations Indoor Air Study (FNIAS) assessed the IAQ and efficacy of air filtration devices in a Manitoba FN using CBPR methods (Weichenthal et al. 2013). This study prioritized the communication of results and community mobilization, and included oral presentations, results workshops, and the dissemination of various knowledge-sharing resources. Other studies have centred CBPR methods as both a data-gathering framework and a knowledge-to-action tool for addressing respiratory health concerns in FN communities (Pahwa et al., 2015, Turner et al., 2020, Katapally et al., 2017). However, no studies have sought to evaluate the effectiveness of using remote (i.e. completely virtual) CBPR methods for research with Indigenous communities. Certainly, remote-adapted CBPR presents challenges and may initially appear paradoxical. Critics of virtual CBPR have noted the reduced capacity for building in-person relationships, and conveying trust, tone, and complex information between researchers and communities (Gruzd & Haythornthwaite 2013). However, it has also been argued that virtual CBPR can transcend geographical barriers to research participation and allow for real-time feedback from communities through prioritized use of instant communication technologies (Tamí-Maury 2017). This study component seeks to assess the feasibility of using virtual CBPR to gather knowledge on IAQ and respiratory health in children living in a FN in Quebec.

KNOWLEDGE GAPS, OBJECTIVES & HYPOTHESES

KNOWLEDGE GAPS

While there have been extensive research projects and surveys conducted on IAQ in the general Canadian population, there is a major knowledge gap in the understanding of IAQ across First Nations. Understanding the general IAP sources, air quality levels, and related health risk profiles are important precedents for the development of policies to minimize adverse health outcomes. This thesis work serves as a pilot for a larger representative study entitled Food, Environment, Health, and Nutrition of First Nation Children and Youth (FEHNCY). FEHNCY is a cross-nation study seeking to characterize the nutrition, environments, and health of FN children and youth over a multi-year period. Moreover, while CBPR has been well-characterized and adapted across multiple contexts, few studies have sought to apply CBPR methods in an entirely remote fashion. However, the COVID-19 pandemic present major barriers to conducting in-person CBPR. As such, it is important to explore methods to adapt CBPR to remote (i.e. virtual) contexts. In collaboration with community leaders, this study seeks to explore the effectiveness of CBPR methods adapted for this purpose.

OBJECTIVES & HYPOTHESES

This research had several objectives. Firstly, it aimed to characterize the indoor air environment in the homes of children and youth living in the Kanesatake First Nation. It was hypothesized that levels of key indoor air pollutants $PM_{2.5}$, PM_{10}, BTEX, and CO_2 in Kanesatake households would show higher levels than those found in the general Canadian household, and that some contaminants would surpass recommended thresholds. It was also hypothesized that exacerbating household conditions would be associated with higher levels of indoor air contaminants.

Secondly, this study sought to determine the relationship between the indoor air environment and pulmonary function of children living in Kanesatake. It was hypothesized that household levels of PM would be inversely related to pulmonary function amongst participating children.

Finally, this study aimed to assess the feasibility of using entirely remote community-based participatory research methods for the collection of indoor air quality data in a FN community.

This thesis is presented in a manuscript format. The work associated with the first two objectives is presented in a manuscript titled "Characterizing the indoor air environment in the homes of children and youth in Kanesatake" in Chapter 2. The work associated with the third objective is presented in a manuscript titled "Assessing the feasibility of using remote CBPR methods for air quality and housing research: Experiences & lessons learned" in Chapter 3.

AUTHOR CONTRIBUTIONS

The responsibilities of the authors included in both manuscripts are as follows: **Rhiannon Ng**: Methodology, investigation, validation, formal analysis, resources, writing – original draft, writing – review and editing; **Jiping Zhu:** Conceptualization, methodology, supervision, writing – review & editing; **Tom Kovesi:** Conceptualization, methodology, supervision, writing – review & editing; **Gary Mallach:** Conceptualization, supervision; **Amy Ing:** Data curation; **Irving LeBlanc:** Conceptualization, supervision; **Tess Lalonde:** Investigation; **Lynn Barwin:** Project administration, funding acquisition, **Hing Man Chan:** Conceptualization, supervision.

CHAPTER 2 | MANUSCRIPT 1

CHARACTERIZING THE INDOOR AIR ENVIRONMENT IN THE HOMES OF CHILDREN AND YOUTH IN KANESATAKE: A PILOT STUDY

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ABSTRACT

Background: Poor indoor air quality (IAQ) is associated with various adverse outcomes, including asthma exacerbation, pneumonia, and other respiratory illnesses. The relationship between housing conditions and IAQ is well-established; however, knowledge about how these determinants affect the health of First Nations children and youth is critically lacking.

Objectives: This study applied community-based participatory research (CBPR) practices to collect information on housing conditions, IAQ, and pediatric respiratory function in the Kanesatake (Kanehsatà:ke) First Nation in Quebec.

Methods: Measurements of key IAQ indicators particulate matter ($PM_{1.0}$, $_{2.5}$, and $_{10}$), CO_2, temperature, relative humidity, and volatile organic compounds (VOCs) were taken in participating households (*n*=31) between June 2021 and January 2022. Questionnaires were administered to collect information on housing conditions.

Results: The mean CO_2 level in participating households was 881.3 (SD 260.0) ppm, with 30% (*n*=9) of homes exceeding the regulatory guidelines for indoor CO_2 (1000 ppm). Mean $PM_{2.5}$ and PM_{10} concentrations in participating households were 29.1 (SD 56.4) $\mu g/m^3$ and 44.5 (SD 88.7) $\mu g/m^{3,}$ respectively, with 60% (*n*=18) of homes exceeding the World Health Organization 1-year standards for ambient $PM_{2.5}$ exposure ($10 \mu g/m^3$). Excessive humidity levels were common in this First Nation, with a mean relative humidity of 52.1 (SD 9.4) %, and 51.6% of households exceeding the Health Canada regulatory guideline.

Conclusions: Despite the small sample size, the preliminary results of this study indicate an urgent need to further understand IAQ levels and sources in First Nations homes and for integrated action towards addressing the health-related impacts of systemic inequality on First Nations children and youth.

INTRODUCTION

Indoor air quality (IAQ) is a critical determinant of physical and mental health in adults and children. Poor IAQ is associated with various adverse health outcomes, including pneumonia, asthma exacerbation, and acute respiratory tract infections (Adaji et al., 2018, Croft et al., 2019). Despite the health risks associated with exposure to IAPs, the characterization of indoor air quality in First Nations communities in Canada has been largely understudied. This is a problematic knowledge gap given the small number of studies showing particulate matter and certain VOC levels in FN households to be several times higher than those measured in the general population (Kovesi et al. 2022, Singleton et al. 2018, Pahwa et al. 2015). Respiratory health has been a significant concern in First Nations populations, with First Nations communities reporting elevated rates of chronic and acute respiratory disorders such as asthma and chronic obstructive pulmonary disease (Bird et al. 2017, Reading et al. 2009, Ospina et al. 2015, Alharbi 2012). Additionally, First Nations and Inuit children have shown elevated rates of respiratory-related hospitalization (Jouvet et al. 2010, Kovesi et al. 2007). The trends in adverse respiratory health in Indigenous communities may be attributable to several underlying factors, including disparate access to primary health care and inadequate and unsuitable housing conditions. Indeed, housing concerns such as poor ventilation, overcrowding, moisture damage and inadequate temperature regulation systems are associated with increased exposures to key IAPs. While poor housing conditions have been documented in First Nations communities (Larcombe et al. 2012, Carrière et al. 2017), there is a need to assess the relationship between poor housing conditions, indoor air quality, and child respiratory health. The lack of information on the levels and predictors of IAP in First Nations households presents significant barriers to community decision-making around these issues.

The primary objective of this study was to characterize the indoor air environment of children and youth in a FN community, focusing on key indoor air pollutants and household conditions. A secondary objective of this study was to assess the respiratory function of children living in participating households to assess respiratory health outcomes. This pilot study was part of the more extensive Food, Environment, Health, and Nutrition of First Nations Children and Youth Study (FEHNCY). FEHNCY is a multi-year pan-Canada project that seeks to understand the impact of the social, built, and natural environments on the health of First Nations children and youth.

Figure 1. Kanesatake Reserve Location. Location in relation to the province of Quebec (A) and location in relation to local waterways and major city (B)

METHODS

Study Design and Community Selection

This cross-sectional pilot study employed a community-based participatory research (CBPR) approach. Community leadership was involved at each stage of the process, including study conception, design, data collection, and knowledge dissemination. To foster integrated knowledge translation and community capacity building, all data were collected by trained community researchers, and community feedback was prioritized in the methodological approach. In early 2020, the Kanesatake FN community leaders expressed interest in participating in the FEHNCY cross-sectional pilot study. Kanesatake was identified as eligible for participation (i.e. situated within an AFN region as of December 31st, 2018) by Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) and was recruited in June 2020 as FEHNCY's pilot community. Kanesatake is located on the north shore of the Ottawa River (**Figure 1**) near Montreal, Canada, and has a population of approximately 1,700 living on reserve.

Co-Governance of Research and Principles of OCAP

All activities related to this study, including its conceptualization, design, and revision, were conducted in close collaboration with First Nations stakeholders, including community leaders and representatives from the Assembly of First Nations (AFN). All procedures followed the First Nations Principles of Ownership, Control, Access, and Possession (OCAP®), which centralizes community members as autonomous agents and owners of all knowledge and data collected within their community. All study staff completed a comprehensive course in OCAP® before joining the project. This study incorporated a multifaceted governance structure to ensure equitable and horizontal input from community leaders and stakeholders, principal investigators, institutions, researchers, and staff at each study phase. Community engagement and an Indigenous Health Promotion (IHP) lens were adapted to promote community mobilization, education, and capacity-building in the context of air quality and health. Community engagement activities were held over the course of the project as a means of building trust, youth interest, and knowledge about the research being conducted.

Community Researcher Recruitment and Training Program

Community researchers (CRs) were hired in early 2020 to oversee the collection of data, monitor study progress, and communicate with the coordinating team. A training program was designed to assist CRs with learning about study backgrounds and methods, including recruitment practices, standard air quality monitoring operating procedures (SOPs), and data management. These SOPs were demonstrated in detail in a series of publicly available training videos that CRs and community leadership had viewed. Information booklets and practice monitors were provided as additional training materials. Two full-day training sessions were carried out over a virtual meeting platform and two follow-up sessions.

Community Engagement & Participant Recruitment

Community engagement began in late 2020 through the dissemination of brochures, radio announcements, and the conduct of participatory activities (such as barbecues at the high school and online photo contests). It continued throughout the duration of study activities. A list of households in Kanesatake was drafted by integrating data from administrative sources. All lists were generated in collaboration with community leaders, members of the AFN housing unit, and FEHNCY team members. The target recruitment sample was n=100. Protocol-specified inclusion criteria were the presence of a child in the household between the ages of 3-19, and the child's self-identification as having FN ancestry. The youngest child was selected for participation in households with multiple children, as adverse respiratory health outcomes are most common in younger populations. CRs contacted participants over the phone, at which time individual informed consent for collecting air quality samples and household information was received.

Indoor Air Quality Data Collection

Air Quality Eggs

Measurements for $PM_{1.0}$, $PM_{2.5}$, PM_{10}, CO_2, relative humidity, and temperature were completed using the Air Quality Egg (AQ Egg Model: 2018). The device consists of a sampling fan and dual Plantower PMS5003 laser sensor, which detects incoming particles using a reflective beam counter. Suspended particles of sizes ranging from 0.3μm to 10μm are quantified by the sensors, and an internal algorithm subsequently generates masses of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} particles in units of $\mu g/m^3$. The instrument's RHT03 MaxDetect sensing technology allowed for the collection of relative humidity and temperature data. These instruments are electrically powered and weather-proof, and store data in long-term internal memory cards. AQ Eggs were deployed in all participating households for a target exposure period of 5 days.

Air Quality Egg Re-deployment

In four households, the particulate matter concentrations were excessively high. To validate these results, AQ Eggs were re-deployed in these four households in May and June 2022 at the time when researchers were in the community for mobile clinic activities. Re-deployment was completed by the Community Researcher (CR). Each household received a different AQ Egg than was deployed during the initial deployment. Household occupants were instructed to place the AQ Eggs once again in a central location on a firm surface and away from fireplaces or wood stoves. The re-deployment period was 5 days.

Volatile Organic Compound Tubes

All VOC samples were collected using commercially available thermal desorption tubes manufactured by PerkinElmer (PerkinElmer Inc, Shelton CT). These desorption tubes have internal diameters of 5.0 mm and a diffusive length of 15.00 mm, and consist of stainless-steel bodies packed with Carbopack B adsorbent resin (mesh size 60/80, No. N9307002). The resin's high temperature stability (up to 400˚C), its high-purity graphite composition, and its hydrophobic properties make it an ideal sorbent for capturing VOCs in environments with high ambient moisture levels. The Carbopack B™ adsorbent also has a relatively strong absorptive strength of 100 m^2/g. All tubes were thermally conditioned before deployment in the community. The study aimed to deploy VOC tubes in 20% of recruited households for an exposure period of 5 days; households were randomly selected for VOC deployment upon recruitment.

After exposure, VOC tubes were shipped to a commercial laboratory for analysis by thermal desorption paired with gas chromatography/mass spectrometry (GC/MS, Agilent gas chromatograph Model:6890 and PerkinElmer desorber Model: ATD650). VOCs were desorbed to the gas chromatography (GC) column following desorption protocols described by Zhu et al. (2013). Desorbed VOCs were then separated using the capillary GC and elution order was analyzed in conjunction with the mass spectrum of each peak and the National Institute for Standards in Technology (NIST) library. VOC levels were converted to µg/m^3 using the FSG/LaBas uptake rates as determined in a previous study (Xian et al. 2011). The conversion was calculated through Equation 3. Exposure time in minutes was calculated from participant questionnaire input.

Equation 3

$$\text{Concentration } (\mu g/m^3) = M/\ (UR \times t)$$

where M = Mass retained on passive sampler (pg), UR = Uptake rate (mL/min), and t =Exposure time (min).

Household Questionnaires

To characterize the indoor environment, a housing questionnaire was administered to each household occupant over the phone by the CR. These questionnaires were developed in collaboration with the AFN to reflect appropriate knowledge-collection practices. This questionnaire was adapted from previous surveys collecting similar information, including the Regional Health Survey (FNIGC, 2018), the Canada Mortgage and Housing Corporation Household Investigation Tool (CMHC, 2022) and a respiratory health questionnaire for children (Ferris, 1978). Specifically, the questionnaire collected key information about household characteristics, including age, building material, and potential predictors of household air quality, such as water damage, ventilation systems, and occupant behaviour. The questionnaires were collected and stored using the KoBo Toolbox secure online database initially developed by the Harvard Humanitarian Initiative (2005).

Outdoor Air Quality Monitor

A weather-resistant outdoor air quality monitor (AQ Egg Model: 2018) was placed in a series of central locations within the community for the duration of the housing and air quality data collection in Kanesatake. Locations were selected based upon their proximity to the community dumpsite, their centrality within the community, presence of an outdoor covering for extra weather protection, and availability of a nearby power outlet. Indoor/Outdoor (I/O) ratios were calculated for particulate matter, carbon dioxide, and relative humidity in each household using the instantaneous levels at the time of data collection to determine the relative contributions of ambient air pollution to the indoor concentrations.

Spirometry Outcomes

Lung function tests for participating children were conducted during the in-community mobile clinic phase of the study in May 2022. EasyOne Air (2001) spirometers were used to measure key lung function parameters. These measurements included Forced Expiratory Volume in 1 second (FEV1), Forced Vital Capacity (FVC), and Maximum Expiratory Flow 25-75% of exhalation (MEF 25-75). Spirometers were checked for calibration at the beginning of each clinic day using a 3L calibration syringe. A maximum of six test trials were performed for each participant. All data was stored securely using EasyOne data collection software. Participants under 6 years of age and participants with difficulties concentrating or following instructions were excluded from the spirometry component.

Data Management and Statistical Analysis

AQ Egg data were stored on a universal serial bus (USB) and downloaded for further analysis at the University of Ottawa. All VOC data were returned from the commercial laboratory in the form of cross-tabular Excel tables. Housing questionnaire data were transferred from the Kobo Toolbox to a secure internet platform (MyCloud) for integration with air quality data. Given minimal pre-existing data on indoor air quality, housing, and health outcomes in FN communities, a sample size requirement could not be determined. All data were compiled into Statistical Analysis Software (SAS), a software suite used for quantitative data management and analysis. Data were then merged in an Excel spreadsheet, and transferred to R for further analysis. R is an open-source programming software that can be used for statistical analysis, as well as generating tables and figures. Air quality data were summarized using means, standard deviations (SDs), medians, and interquartile ranges. Categorical variables were summarized using percentages and frequencies. Data were assessed for normality using Shapiro-Wilk tests for normality, along with quantile-

quantile plot normality visualizations. All PM values, along with relative humidity, failed the Shapiro-Wilk test for normality (**Table S1**) and skewness was visualized through Q-Q plots (**Figures S1 & S2**). Left-skewed and were log-transformed for further analysis. Relative humidity data were highly right-skewed and were transformed using a square-root transformation for further analysis. Pearson correlation coefficients were used to assess relationships between quantitative, continuous variables for all AQ Egg-measured variables. Exceedance percentages were determined through comparison with national and international recommended values. Direct comparison of Kanesatake air quality levels with CHMS data was conducted using medians and geometric means due to large discrepancies in sample sizes. To minimize the occurrence of Type I errors in a stepwise regression model, common household risk factors were determined *a priori* for integration into the model and multivariate analysis. These risk factors included presence of a smoking guardian, woodstove and fireplace use, presence of a heat recovery ventilator (HRV), and occurrence of floods and leaks. A forward stepwise regression model was built to determine the statistical influence of household predictors on air quality levels. A significance level of $p=0.1$ was required for entry and removal of predictors in the model at subsequent steps. A multivariate regression was used to model the outcome of indoor air levels with the presence or absence of several household predictors. Statistical relationships between dichotomous VOC measurements and housing conditions were limited to the descriptive phase due to sample size restraints.

Ethics Approval

This project was designed to ensure the highest standard of community-based participatory research ethics and integration of community interests, desires, and protocols. Ethics approval was obtained from all partner institutions, namely, the Research Ethics Board of Health Canada, the Children's Hospital of Eastern Ontario, the University of Ottawa, University of Laval, McGill

University, and l’Université de Montreal. The study was approved by the Assembly of First Nations in Resolution 04/2019 at the Annual General Assembly in Fredericton, New Brunswick.

COVID-19 Adaptations

All study proceedings were adapted to minimize the risk of COVID-19 transmission for all staff and participants. While initially the project methods involved extensive travel and in-person engagement with the community, the COVID-19 pandemic required unexpected adaptation of all methods to a remote (i.e. virtual) setting. All air quality and housing questionnaire data were collected remotely by trained CRs, with no external researchers visiting the community. All CR training procedures and community engagement activities were likewise conducted online through video-sharing platforms, social media, and other communication technologies. Special sanitation protocols were approved for the handling of monitors before mailing to communities, at various stages of handling and deployment, and upon receiving monitors back at the University of Ottawa. The mobile clinic was run on-site in May 2022. All attending staff were vaccinated against COVID-19, and precautions were taken to minimize the risk of transmission, including the installation of ventilators in each clinic room, maintaining physical distancing measures, and always wearing N95 masks.

Data Quality Control

For the AQ Eggs, no duplicate or blank samples were deployed due to a limited number of available instruments. For the model used in this study, the intra-model variability is established by the manufacturing company at 4-8% (AQ Sensor Performance Evaluation Center 2018). Three trip VOC blanks were sent to Kanesatake and were included in the analysis; blank samples were prepared, handled, and analyzed using identical procedures to the exposed samples to identify any contamination associated with field deployment. The limit of detection (LOD) for VOC tubes was estimated by the commercial lab. Blank corrections were applied by subtracting mean blank sample levels, and any corrected values less than the instrument's limit of detection were replaced with ½ limit of detection for further analysis. Five duplicate VOC tubes were deployed, and relative percent differences (RPDs) between duplicates and samples were used to calculate precision using Equation 1:

Equation 1

$$RPD\ (\%) = (sample\ result - duplicate\ result)\ *\ 100\ /(sample\ result + duplicate\ result/2)$$

Relative to alternate sensor technology, the AQ Egg PM sensors are relative humidity-dependent. As such, a PM correction factor derived by the University of Northern British Columbia (UNBC) and Environment Climate Change Canada (ECCC) was applied to control this factor and improve representativeness of AQ conditions and comparability between AQ EGG data and measurements taken using alternate instruments (UNBC, 2017). The following correction factor was applied (Equation 2):

Equation 2

$$PM_{2.5} = AQ\ Egg\ PM_{2.5}/(1+0.24/(100-RH-1))$$

where RH = relative humidity over the sampling period.

RESULTS

Recruitment Results

The in-community recruitment period began in June 2021 and ended in January 2022. Of the 510 homes in Kanesatake, 82.9% (n=427) were not eligible for participation, and 4.7% (n=24) were vacant. Primary reasons for non-eligibility were absence of a child between 3-19 years of age in the household (95.8%, n=409) and non-identification as FN (4.2%, n=18). Of the remaining eligible homes, 83 households (31.3%, n=26) could not be contacted by phone upon several attempts. This resulted in n=57 eligible and contacted homes, of which 33 (61.1%) were enrolled into the study. Two participants later withdrew from the air quality component, resulting in a final participation sample of n=31 (**Figure 2).**

Of the 31 participating children, 27.3% were between the ages of 3 and 5, while the remaining 72.7% were between the ages of 6 and 19. Additionally, 57.6% of children identified as male and the remaining 42.4% identified as female (**Table 1**). The mean number of children in each enrolled household was 2.09 (minimum = 1, maximum = more than 6).

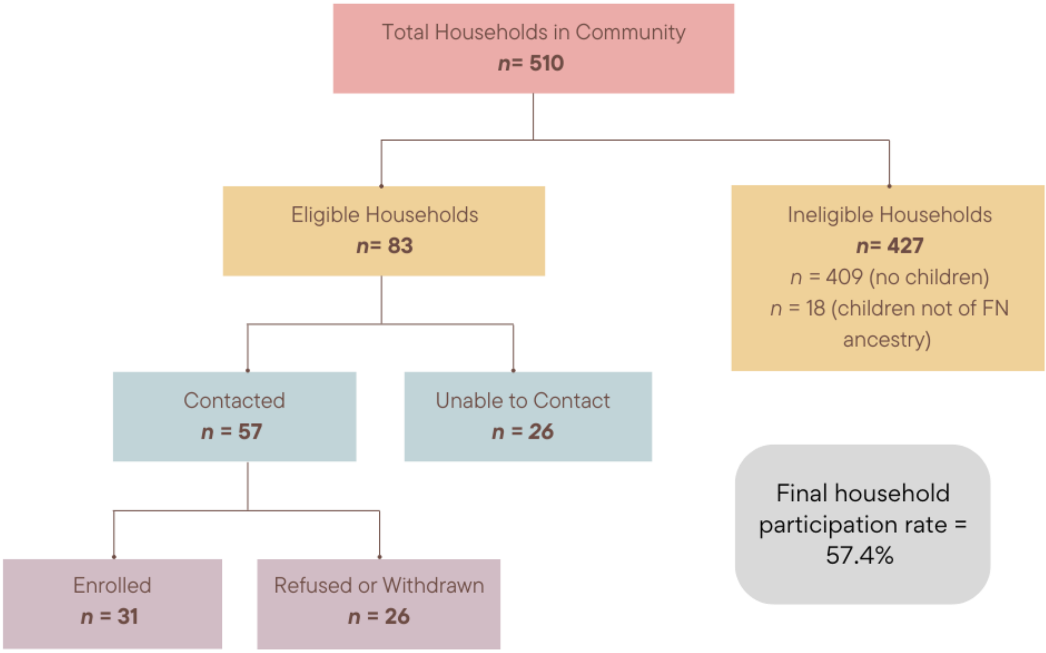


Figure 2. Household participation flowchart for questionnaires and IAQ measurements. The final participation rate for this component was 57.4% (n = 31).

Table 1. Characteristics of Participants. Of the 31 children enrolled in the IAQ component, 42.4% were between the ages of 12-19.

CHARACTERISTICS OF PARTICIPANTS		
Participant Age Group	N	Percent (%)
Aged 3-5 years	9	27.3
Aged 6-11 years	10	30.3
Aged 12-19 years	12	42.4
Participant Sex		
Female	14	42.4
Male	17	57.6

IAQ Measurements

Two households enrolled in the study later withdrew from the air quality component. Air Quality Eggs were therefore deployed in 31 households for a mean exposure period of 6.26 days (minimum = 5, maximum = 11). One AQ Egg malfunctioned during the exposure period and was re-deployed in May 2022 outside the official data collection timeframe.

The mean $PM_{2.5}$ concentration across households after applying the humidity correction factor was 29.1 µg/m^3 (± 56.4 µg/m^3), with a mean peak value of 258 µg/m^3 (+/- 247 µg/m^3). The mean PM_{10} concentration across all households was 44.5 µg/m^3 (± 88.7), with a mean peak value of 459 µg/m^3 (± 445 µg/m^3). Carbon dioxide values across households averaged 884 ppm (± 526 ppm). Mean peak value for CO_2 was 1631 ppm (± 659 ppm). Mean relative humidity values were

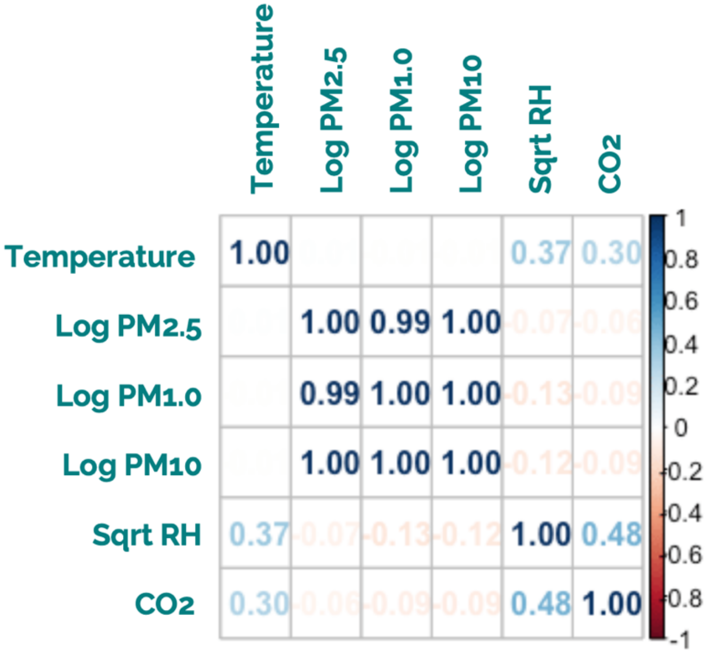
52.4% (± 9.44%), with a mean peak concentration of 66.0% (± 9.32%). Summaries are described in **Table 2.**

Regression analysis using transformed variables showed weak positive associations between temperature and relative humidity, and temperature and CO_2 (R^2 = 0.37 and 0.30, respectively, **Figure 3**). A moderately positive association between CO_2 and relative humidity was also observed and further visualized (R^2 = 0.48, **Figure 4**).

Table 2. Indoor Air Measurements (n=31).

SUMMARY OF AQ EGG MEASUREMENTS				
AQ Variable*	Mean ± SD	Median (1st-3rd Quartile)	Maximum Observed Mean	Mean Peak Values ± SD
$PM_{2.5}$ (μg/m^3)	29.1 ± 56.4	9.24 (5.22 - 24.9)	299	258 ± 247
PM_{10} (μg/m^3)	44.5 ± 88.7	14.8 (6.59 - 33.8)	470	459 ± 445
$PM_{1.0}$ (μg/m^3)	17.4 ± 25.3	7.79 (3.95 - 19.0)	126	197 ± 181
CO_2 (ppm)	884 ± 256	800 (681 - 1074)	1443	1631 ±659
Relative humidity (%)	52.4 ± 9.44	55.2 (47.6 - 58.1)	64.1	66.0 ± 9.32
Temperature (˚C)	22.3 ± 1.9	22.5 (20.9 - 23.6)	25.9	25.3 ± 2.53

*The AQ Egg was used to measure the following air quality indicators



	Temperature	Log PM2.5	Log PM1.0	Log PM10	Sqrt RH	CO2
Temperature	1.00	[illegible]	[illegible]	[illegible]	0.37	0.30
Log PM2.5	[illegible]	1.00	0.99	1.00	-0.07	-0.06
Log PM1.0	[illegible]	0.99	1.00	1.00	-0.13	-0.09
Log PM10	[illegible]	1.00	1.00	1.00	-0.12	-0.09
Sqrt RH	0.37	-0.07	-0.13	-0.12	1.00	0.48
CO2	0.30	-0.06	-0.09	-0.09	0.48	1.00

Figure 3. Pearson Correlation Matrix for all IAQ Variables. Weak or negative correlations were observed between particulate matter variables and temperature, relative humidity, and carbon dioxide.

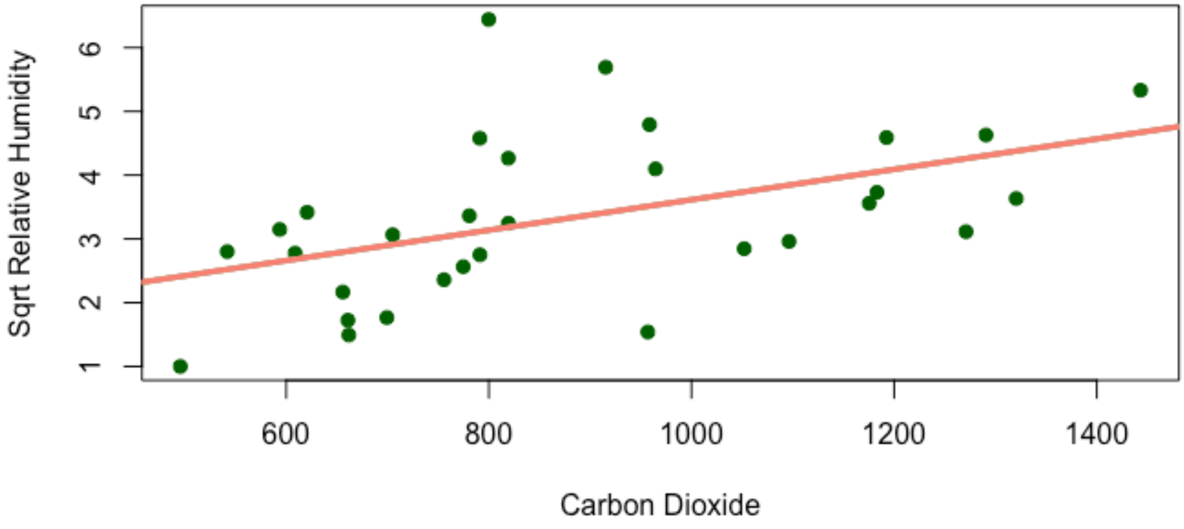


Figure 4. Relationship between relative humidity and carbon dioxide. Pearson correlation = 0.48 for these variables; moderately positive correlation.

IAQ Re-Deployment

The average re-deployment exposure period was 4.25 days. Mean particulate matter values from both initial and re-deployment periods across all four homes are summarized in **Table 3**. Mean total PM values were lower in the re-deployment data in all four households. The peak $PM_{2.5}$ levels also decreased in each household. Household (HH) 11186 showed a large decrease of 92.6% in mean $PM_{2.5}$, followed by HH 11314 (71.9%), HH 11059 (39.8%), and HH11053 (31.6%). Follow-up questionnaires indicate that occupants in HHs 11053 and 11059 smoke indoors for at least 3 hours per day. Additionally, 11053 and 11314 reported using a woodstove or fireplace during the first deployment, but not during the re-deployment period. The follow-up questionnaire for HH 11186 was not completed by the CR.

Table 3. PM summaries for initial and re-deployment periods in four homes in Kanesatake. Households initially showed excessively high PM readings and monitors were de-deployed to confirm these readings.

Household ID	Mean $PM_{2.5}$ ($\mu g/m^3$)	Maximum $PM_{2.5}$ Observed ($\mu g/m^3$)	Percent Decrease in Mean $PM_{2.5}$ (%)	Mean $PM_{1.0}$ ($\mu g/m^3$)	Mean PM_{10} ($\mu g/m^3$)
11053 (1)	389.9	1233.7	31.6	125.7	470.0
11053 (2)	266.7	1047.1		125.6	324.2
11059 (1)	136.8	763.6	39.8	64.7	164.7
11059 (2)	82.4	456.9		45.2	93.8
11186 (1)	124.9	877.7	92.6	47.0	155.3
11186 (2)	9.3	499.3		5.4	10.4
11314 (1)	72.2	576.6	71.9	40.2	83.6
11314 (2)	23.3	264.0		14.3	26.8

Exceedance Rates of IAQ Levels & Comparison to General Population

Exceedance rates for air quality contaminants measured in Kanesatake are summarized in **Table 4**, as compared to threshold values recommended by Health Canada and the World Health Organization. Under Health Canada's jurisdiction, $PM_{2.5}$ and PM_{10} are considered non-threshold contaminants, and it is recommended that indoor levels be kept as low as possible.. In Kanesatake, 45.2% of the homes (n=14) exceeded the WHO recommendation of 15 µg/m^3 for 24-hr exposure in ambient air. A smaller proportion of households (22.6%, n=7) exceeded the WHO recommendation of 45 µg/m^3 for a mean 24-hour PM_{10} exposure. There were 9 homes in the community with mean CO_2 values above the Health Canada recommended average of 1000 ppm, and over half of households (51.6%, n=16) exceeded Health Canada's recommended guideline for relative humidity. Of the nine households with CO_2 exceedances, relative humidity exceedances were observed in four. The mean $PM_{2.5}$ levels across Kanesatake households were higher than the mean levels found by studies conducted in different Canadian cities by Health Canada (<15µg/m^3) (Health Canada, 2012)..

Table 4. Exceedance for IAQ levels measured in Kanesatake, as compared to thresholds recommended by national and international policymakers.

AQ VARIABLE	Mean Observed in Kanesatake	Health Canada Recommendations	World Health Organization Recommendations**	Exceedance Percentage (n)
*$PM_{2.5}$ (µg/m^3)	29.1	Keep levels as low as possible	5 µg/m^3 annual mean 15 µg/m^3 24-hour mean	45.2 (14) *for WHO 24-hr guidelines*
*PM_{10} (µg/m^3)	44.5	Keep levels as low as possible	15 µg/m^3 annual mean 45 µg/m^3 24-hour mean	22.6 (7) *for WHO 24-hr guidelines*
CO_2 (ppm)	884	< 1,000 24-hour mean	< 1,000 24-hour mean	29.0 (9)
Relative Humidity %	52.4	< 55	--	51.6 (16)

**WHO recommendations for $PM_{2.5}$ exposure in outdoor air are commonly used as proxies for exposure threshold comparisons in Canada.

Summary of VOC Results

Volatile Organic Compound (VOC) tubes were deployed in 14 households for an average exposure period of 6.26 days. Volume-adjusted measurements for all VOCs are described in **Table 5**. Among the measured VOCs, decamethylcyclopentasiloxane (D5) was found to be the most abundant, with a detection frequency of 100% and geometric mean (GM) concentration of 23.54 µg/m^3. This was followed by toluene, octamethylcyclotetrasiloxane, (D4) and m- and p-xylene, at 14.66, 12.76, and 10.83 µg/m^3, respectively. O-xylene was detected at a 92.86% frequency, with a geometric mean value of 3.78 µg/m^3. All remaining BTEX compounds (benzene and ethylbenzene) were detected at frequencies of 100%, as were hexane, camphene, heptane, and 1,3-butadiene-2-methyl. The sum of the geometric means for the ten compounds detected at 100% (77.9 µg/m^3) accounted for 41.8% of the total GM value for the VOCs detected at over 50% frequency, and 40.8% of the total GM for all detected VOCs. Other important VOCs were found at notable detection frequencies. Alpha-pinene was detected at a frequency of 92.86%, with a GM concentration of 10.09 µg/m^3. Similarly, styrene was detected at a frequency of 78.57%, with a GM concentration of 1.26 µg/m^3. Naphthalene was present at a detection frequency of 72.4%, with a GM concentration of 0.55 µg/m^3. Strong positive relationships were observed in all BTEX compounds when analyzed against one another for co-occurrence (R^2 = > 0.9 for all BTEX). VOCs detected at frequencies of <50% and at 0% are summarized in **Table 6** and **Table 7.**

Nicotine was detected in 21.43% of homes at GM concentration of 0.81 µg/m^3.

Table 5. Characteristics of VOC levels in Kanesatake households selected for VOC monitoring. Compounds shown below had Detection Frequency (DF) >50%.

VOC Name	DF	Arithmetic Mean	Geometric Mean	SD	Median	Lower 95% CI	Upper 95% CI	25th Ptl	50th Ptl	75th Ptl	90th Ptl
	%	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3
1,3-Butadiene-2-methyl	100.00	6.05	4.69	4.1	5.9	3.42	8.26	2.19	5.91	9.30	12.45
Benzene	100.00	4.93	2.93	7.1	2.7	0.73	8.95	2.07	2.66	5.33	17.95
Camphene	100.00	2.96	1.92	3.5	1.6	0.81	4.92	1.18	1.64	3.39	9.75
Decamethyl cyclopentasiloxane	100.00	130.55	23.54	265.3	32.7	-31.20	278.29	4.83	32.66	93.05	690.04
Octamethyl Cyclotetrasiloxane	100.00	46.34	12.76	91.9	10.1	-14.97	83.55	4.18	10.09	31.44	248.40
Ethylbenzene	100.00	5.16	2.66	8.5	2.6	0.11	9.97	1.41	2.63	5.34	20.60
Heptane	100.00	4.22	2.20	7.7	1.9	-0.38	8.62	1.31	1.93	3.44	18.07
m-Xylene & p-Xylene	100.00	21.60	10.83	34.9	11.1	-0.12	40.12	5.00	11.10	21.61	90.42
Hexane	100.00	6.01	1.71	15.7	1.2	-3.14	15.05	0.67	1.17	3.97	32.48
Toluene	100.00	32.38	14.66	65.5	12.1	-6.27	69.51	6.48	12.12	25.24	149.67
Alpha-pinene	92.86	21.73	10.09	22.9	9.1	5.96	32.72	4.00	9.11	38.20	64.74
1-Hexanol-2-ethyl	92.86	3.99	2.31	4.5	2.6	1.10	6.45	1.13	2.60	5.37	13.20
Acetone	92.86	10.72	8.56	7.3	9.9	4.13	12.59	4.89	9.87	14.54	22.71
Carbon Tetrachloride	92.86	0.46	0.38	0.4	0.3	0.26	0.67	0.30	0.34	0.46	1.15
d-Limonene	92.86	64.12	32.60	74.8	39.7	18.27	105.45	23.83	39.72	67.76	229.79

VOC Name	DF	Arithmetic Mean	Geometric Mean	SD	Median	Lower 95% CI	Upper 95% CI	25th Ptl	50th Ptl	75th Ptl	90th Ptl
	%	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³
Furfural	92.86	2.79	2.11	1.8	2.4	1.26	3.35	1.73	2.45	3.44	6.14
Heptanal	92.86	2.28	1.62	2.2	2.0	0.88	3.51	0.93	1.98	2.61	6.18
Hexanal	92.86	9.18	5.24	8.8	6.1	3.21	13.67	3.08	6.13	13.70	25.65
Isopropyl Alcohol	92.86	54.64	5.97	181.3	4.2	-50.68	158.61	2.31	4.16	9.41	354.91
Nonanal	92.86	5.20	3.07	6.6	3.6	1.41	9.05	1.64	3.62	6.12	17.23
o-Xylene	92.86	6.94	3.78	10.7	3.2	0.01	12.30	1.94	3.24	7.10	27.95
Octanal	92.86	2.40	1.69	2.2	1.8	0.97	3.60	0.87	1.81	3.04	6.46
Pentane	92.86	22.07	7.87	37.7	4.9	-3.72	39.90	2.82	4.94	23.48	103.57
Phenol	92.86	2.22	1.52	2.1	1.5	0.86	3.39	1.11	1.54	2.39	6.76
1-Butanol	85.71	4.45	2.17	6.0	2.8	0.22	7.11	0.90	2.77	5.59	15.70
2-Butanone	85.71	1.62	0.87	1.5	1.1	0.59	2.87	0.31	1.15	2.93	4.08
2-Pentanone	85.71	0.86	0.58	0.7	0.7	0.37	1.22	0.26	0.70	1.30	2.23
Cyclohexane	85.71	2.56	0.63	7.1	0.5	-1.55	6.64	0.34	0.48	1.29	14.40
2-Heptanone	78.57	0.72	0.53	0.5	0.7	0.37	0.94	0.24	0.75	1.06	1.55
Benzaldehyde	78.57	4.51	1.93	5.4	3.7	1.25	7.48	0.59	3.71	5.95	14.79
Ethane,1,2-dichloro	78.57	0.69	0.46	0.7	0.5	0.28	1.06	0.24	0.49	0.86	2.08
Octane	78.57	1.59	1.06	1.9	1.0	0.17	2.39	0.50	1.02	1.72	5.43
Styrene	78.57	1.26	1.26	0.9	1.2	0.61	1.71	0.52	1.21	2.01	2.72
1-Pentanol	71.43	1.57	0.75	1.8	1.0	0.32	2.31	0.11	1.02	2.34	4.89
1-Propanol-2-methyl	71.43	0.88	0.55	0.8	0.8	0.37	1.30	0.26	0.80	1.04	2.47

VOC Name	DF	Arithmetic Mean	Geometric Mean	SD	Median	Lower 95% CI	Upper 95% CI	25th Ptl	50th Ptl	75th Ptl	90th Ptl
	%	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
Benzene-1-3-5-trimethyl	71.43	1.34	0.61	2.4	0.6	-0.05	2.69	0.24	0.61	1.06	6.01
Chloroform	71.43	0.43	0.27	0.5	0.3	0.13	0.70	0.09	0.25	0.57	1.39
Dodecane	71.43	0.89	0.62	0.8	0.6	0.35	1.28	0.22	0.60	1.34	2.34
Naphthalene	71.43	0.78	0.55	0.7	0.6	0.32	1.14	0.23	0.55	1.13	2.07
Nonane	71.43	2.73	1.40	3.7	1.3	0.11	4.53	0.70	1.27	3.02	10.76
2-Propanol-2-methyl	64.29	1.11	0.42	1.9	0.5	-0.04	2.11	0.09	0.53	1.48	4.46
Benzene-1,2,3-trimethyl	64.29	1.47	0.69	2.3	0.8	0.09	2.84	0.17	0.80	1.22	6.43
Decane	64.29	5.30	2.26	9.2	2.3	-0.97	9.83	0.68	2.34	3.66	25.26
Methyl Isobutyl Ketone	64.29	0.95	0.42	1.6	0.4	-0.03	1.87	0.12	0.41	1.23	3.97
1-Propanol	57.14	0.98	0.75	0.9	0.7	0.19	2.20	0.37	0.75	1.23	2.67
2-Butanol	57.14	0.27	0.21	0.2	0.3	0.13	0.39	0.09	0.27	0.31	0.73
1, 4-Dioxane	50.00	0.24	0.18	0.2	0.2	0.11	0.34	0.08	0.18	0.39	0.60
2-Hexanone	50.00	0.32	0.24	0.2	0.3	0.14	0.42	0.12	0.28	0.44	0.76
Decanal	50.00	0.60	0.39	0.7	0.3	0.20	1.03	0.18	0.35	0.72	1.98
Undecane	50.00	4.71	2.05	7.6	1.9	-0.82	7.80	0.75	1.86	4.44	20.94

SD = Standard Deviation, CI = Confidence Interval, Ptl = Percentile.

Table 6. Statistical description of levels of Volatile Organic Compounds with Detection Frequency (DF) <50%.

VOC Name	DF %	75th Ptl µg/m^3	90th Ptl µg/m^3	Maximum Observed µg/m^3
1-Butanol-3-methyl	35.71	0.47	1.67	1.67
Cyclohexanone	35.71	0.69	3.78	5.13
Tetrachloroethylene	35.71	0.44	1.62	2.07
1-Methyl-2-pyrrolidinone	28.57	0.20	0.69	0.86
2-Butoxyethanol	28.57	1.57	2.69	2.73
2-Pentanol	28.57	0.32	0.64	0.65
Cumene	28.57	0.26	0.95	1.47
Furan-2,5-dimethyl	28.57	0.24	0.56	0.71
Nicotine	21.43	1.08	2.66	3.78
Tetrahydrofuran	21.43	0.14	0.52	0.59
Trisiloxane Octamethyl	21.43	0.31	12.83	17.30
Benzene-1-4-dichloro	14.29	< MDL	12.72	18.73
Benzofuran	14.29	< MDL	0.19	0.26
Furan-3-methyl	14.29	< MDL	0.20	0.28
Trichloroethylene	14.29	< MDL	0.42	0.62
Biphenyl	7.14	< MDL	0.48	0.80
Quinoline	7.14	< MDL	0.56	1.00
Tetrasiloxane Decamethyl	7.14	< MDL	0.86	1.43

SD = Standard Deviation, CI = Confidence Interval, Ptl = Percentile; MDL = Method Detection Limit; MDL was <1 for all compounds below with the exception of nicotine (<5).

Table 7. List of VOCs with Detection Frequency = 0%.

VOC Name			
Geosmin	Chlorobenzene	3-Octanone	2-Methylisoborneol
1-Nonanol	Cyclohexanol	Benzene-1-2-4-trimethyl	2-Nonanone
1-Octanol	Decane-1-bromo	Benzene-1-2-dichloro	Ethane-1,2-dibromo
1-Octen-3-ol	Disiloxane Hexamethyl	Bromoform	Ethane-hexachloro
1-Propene-2,3-dichloro	Ethane-1,1,1,2-tetrachloro	Ethene-1,1-dichloro	Propane-1,2-dichloro
2-Butanol-2-methyl	Ethane-1,1,2-trichloro	Methane Bromodichloro	
2-Butanol-3-methyl	Ethane-1,1-dichloro	Methane Dibromochloro	

Kanesatake VOCs in a National Context (Compared to CHMS)

Examination of VOC levels in Kanesatake in the context of nationally representative data is limited due to the small sample size (n=14). However, when considering the geometric means (GM) for each compound, some patterns were observed. The GM was used for the comparison as it provides a more accurate description of the central tendency in small sample sizes. All BTEX compounds were observed at higher GM concentrations in Kanesatake compared to average Canadian homes (**Figure 5**). Toluene levels in Kanesatake were 1.8 times higher than those found by the Canada Health Measures Survey (CHMS) when comparing GMs. Similarly, benzene levels in Kanesatake were over twice as high (2.93 µg/m^3) compared to those found in the average Canadian home (1.94 µg/m^3). Additionally, ethylbenzene and m- and p-xylene levels were observed at 2.66 µg/m^3 and 10.83 µg/m^3 in Kanesatake, while their respective levels in CHMS data are 1.23 µg/m^3 and 4.23 µg/m^3.

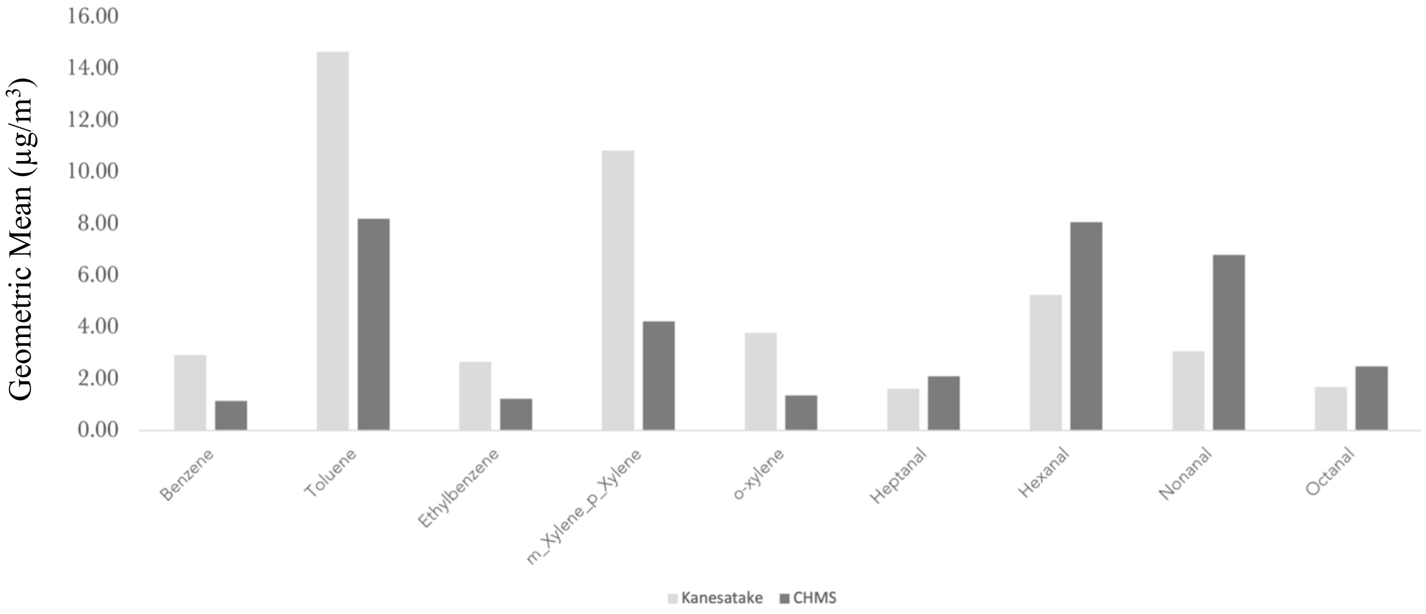


Figure 5. Comparison BTEX and aldehydes levels in Kanesatake to CHMS data. Geometric means were compared due to the large discrepancy in sample size.

In the CHMS, limonene was the most abundant VOC found across households, with a GM of 23.9 µg/m^3 with a DF of 99.9%. While limonene was detected in only 92.2% of homes in Kanesatake, its GM concentration was detected at a higher level of 32.6 µg/m^3. On the other hand, some compounds in Kanesatake were detected at lower levels than the nationally representative GMs. VOCs in this category include key aldehydes hexanal (5.24 µg/m^3 and 8.07 µg/m^3 in Kanesatake and Canadian homes, respectively), benzaldehyde (1.93 µg/m^3 and 2.48 µg/m^3), nonanal (3.07 µg/m^3 and 6.80 µg/m^3), and octanal (1.69 µg/m^3 and 2.69 µg/m^3). Of the Health Canada-regulated VOCs, none of the compounds measured in any households in Kanesatake exceeded the recommended indoor guidelines. Specifically, the Health Canada proposed guidelines for residential indoor xylene exposure over 24hrs is 150 µg/m^3 (Health Canada, 2022), while that for toluene is 2,300 µg/m^3 (Health Canada, 2012). Benzene is considered a non-threshold chemical and is thought to exert effects at all levels of exposure. Health Canada recommends that benzene levels be kept as low as possible in the indoor environment.

Outdoor Air Quality Results

The outdoor air quality monitor was deployed in six central locations throughout the data collection period (**Figure 6**). Locations 1 and 2 were proximal to the local landfill. The outdoor measurements are summarized in **Table 8.** Mean outdoor $PM_{2.5}$, PM_{10}, and CO_2 concentrations across the study period were 10.3 µg/m^3, 11.5 µg/m^3, and 523.6 ppm, respectively. While there was no notable relationship between mean PM levels and distance from the dump, one deployment at Location 2 showed considerably higher $PM_{2.5}$ and PM_{10} levels (18.6 and 21.8 µg/m^3, respectively. The lowest mean PM levels were observed at Location 3, where the mean $PM_{2.5}$ level was 6.03 µg/m^3 and the mean PM_{10} level was 6.56 µg/m^3.

Figure 6. Locations of outdoor air quality monitors. The location of the dumpsite is indicated by the solid green circle. Locations 1101, 1102, 1103, and 1106 were selected due to their proximity to the dumpsite.

Table 8. Descriptive summary of outdoor air quality measurements taken in Kanesatake. Measurements were taken at six central locations over the course of the study data collection period.

Location ID	Monitor ID	Start Date	End Date	Mean Temperature (C˚)	Mean Humidity (%)	Mean $PM_{2.5}$ ($\mu g/m^3$)	Mean PM_{10} ($\mu g/m^3$)	Mean $PM_{1.0}$ ($\mu g/m^3$)
LOCATION 1	**1101**	10/04/2021	10/08/2021	**15.6**	68.7	8.56	9.18	5.76
	1102	10/19/2021	10/25/2021	21.6	71.3	8.81	9.49	5.59
LOCATION 2	**1103**	11/04/2021	11/11/2021	6.67	61.8	9.73	11.0	6.32
	1106	12/28/2021	01/11/2022	-5.59	61.0	18.6	21.8	11.1
LOCATION 3	**1104**	11/17/2021	11/22/2021	8.40	68.6	6.03	6.56	3.66
LOCATION 4	**1105**	12/13/2021	12/18/2021	2.59	59.9	9.89	11.2	5.73

Housing Questionnaire Results

The housing questionnaire was completed for all 31 households with completed indoor air quality measurements. Key results are summarized in **Table 9.** Of these 31 households, 25.9% (*n*=8) were reported needing major repairs. Participating households generally lacked adequate indoor ventilation and dehumidification means. While most households had a working kitchen fan (65%, *n*=20), only two households reported being equipped with working heat recovery ventilators (HRVs), and 42% of households (*n*=13) had working dehumidifiers. Additionally, 42% (*n*=13) of households reported being situated in proximity to dusty roads or industrial facilities which caused a degree of concern to occupants. Over half of homes (61%, *n*=19) reported mould problems in their houses, and over half had had a leak or a flood in their household in the past. The presence of pets in the household was ubiquitous (87%, *n*=27), as was the use of chemicals in the house at least once in the two weeks before the AQ data collection and household survey (>60%). Finally, there was at least one smoking guardian in 42% of homes (*n*=13), and in 13% (*n*=4) homes, the mother and father smoked.

Table 9. Housing questionnaire results from occupants in Kanesatake (n = 31).

EXPOSURE VARIABLE	NO. OF PARTICIPANTS (%)	NO. OF MISSING VARIABLES (%)
Household in proximity to source of dust or fumes	13 (42%)	0 (0)
Mould problems	19 (61%)	0 (0)
Primary Heating Type		0 (0)
Electric baseboards	19 (61%)	
Forced-air furnace	7 (23%)	
Hot water radiators	1 (3.2%)	
Woodstove	2 (6.5%)	
Fireplace	1 (3.2%)	
Space heaters	1 (3.2%)	
Secondary Heating Type		12 (39%)
Electric baseboards	5 (16%)	
Forced-air furnace	1 (3.2%)	
Gas stove	2 (6.5%)	
Woodstove	5 (16%)	
Fireplace	2 (6.5%)	
Space Heaters	3 (9.7%)	
Other	1 (3.2%)	
Cooking Fuel Used		0(0)
Electricity	29 (94%)	
Bottled tank or liquid propane gas	1 (3.2%)	
Both	1 (3.2%)	
Reported Presence of Working Heat Recovery Ventilator	2 (6.5%)	0 (0)
Presence of Working Kitchen Fan	20 (65%)	5 (16%)
Presence of Working Dehumidifier	13 (42%)	0 (0)
Water considered safe for drinking	15 (48%)	0 (0)
Guardian Smokes		0 (0)
Mother	5 (16%)	
Father	4 (13%)	
Both	4 (13%)	
Presence of Pets in Household	27 (87%)	0 (0)
Presence of Attached Garage	7 (23%)	0 (0)
Household Products Used in the Past Month		0 (0)
Candles	19 (61%)	
Gasoline or Gasoline-Powered Devices	1 (3.2%)	
Propane or Propane-Powered Devices	2 (6.5%)	
Moth balls	1 (3.2%)	
Oil-based paints	2 (6.5%)	
Latex Paint	4 (13%)	
Paint remover	1 (3.2%)	
Solvents	1 (3.2%)	
Oil-Based wood stains	4 (13%)	

Housing and Indoor Air Quality

The forward stepwise regression model indicated that the presence of one or more smoking guardians in the household was a significant predictor of poor indoor $PM_{2.5}$ concentrations (**Table 10**, $\beta = 1.27$, SE = 0.367, $p=0.002$). The same was true of PM_{10} ($\beta =1.26$, SE = 0.39, $p=0.003$). The forward stepwise regression analysis also included the use of chemicals in the house ($\beta = 0.80$, $p=0.055$) and the presence of pets ($\beta =1.0$, $p=0.073$) as predictors of indoor $PM_{2.5.}$ The same predictors were retained in the model for PM_{10} (**Table 10)**. Due to the small sample size of collected VOCs, statistical analyses between VOC levels and household predictors were limited. However, preliminary analysis of the relationship between key VOCs and indoor CO_2 levels showed some relationships. CO_2 and benzene showed a weak positive correlation ($R^2 = 0.48$), while CO_2 and styrene showed a stronger positive relationship ($R^2 = 0.79$). The relationship between CO_2 and all xylenes, as well as ethylbenzene, showed weak relationships of $R^2 = \leq 0.3$. Additionally, while the presence of one smoking guardian was not positively correlated with BTEX, styrene, or indoor naphthalene levels, the presence of two smoking guardians (n=1) showed a strong positive correlation with indoor VOCs. VOC levels were highest in this household for all key VOCs (i.e. BTEX, styrene, and naphthalene). Specifically, benzene, ethylbenzene, and m,p-xylene levels were at least four times higher than those found in the households with second-highest readings for these VOCs. Importantly, this household also had mean CO_2 levels exceeding the 1000 ppm national guideline.

Table 10. Relationship between smoking and PM levels and reported household predictor variables.

STEPWISE REGRESSION SUMMARY				
Variable	Predictor	Beta	Std. Error	Sig.
$PM_{2.5}$	Presence of one or more smoking guardians or adults in household	1.27	0.37	0.002*
	Presence of pets	1.00	0.53	0.073
	Use of chemicals in the home in the past 2 weeks	0.80	0.40	0.055
PM_{10}	Presence of one or more smoking guardians or adults in household	1.26	0.39	0.003*
	Presence of pets	1.07	0.573	0.072
	Use of chemicals in the home in the past 2 weeks	0.86	0.42	0.052

Mobile Clinic and Spirometry Results

The mobile clinic was conducted at the Kanesatake Health Centre between May 25th and June 3rd 2022. Participants in the housing component, as well as volunteers, were included in the mobile clinic data collection. Of the 19 participants, 14 were eligible for inclusion in the spirometry data collection. The primary reasons for exclusion were children below the age of 6 and a child's inability to cooperate or perform the test due to concentration challenges. Of the 14 spirometry tests conducted, 11 were intelligible (i.e., produced readable flow-volume curves), and of these 11 children, 7 were FEHNCY participants, and 4 were volunteers (**Figure 7**). The total retention rate of mobile clinic participants from the housing and air quality component was 22.5%. Spirometry results across eleven tests are summarized in **Table 11**. The mean FVC was 105% (+/- 18.5), and the mean FEV1 was 104% (+/- 15.7). The mean MEF 25-75 was 105% (+/- 22.0). Upon consultation with a clinical respirologist, one participant was referred for a non-urgent follow-up due to mild air flow obstruction (FVC, FEV1). For all spirometry tests, the FVC, FEV1, and MEF

25-75 values are presented as percentages of the predicted values for each participant's reference demographic, with the mean being 100% predicted and the normal range being 80-120% predicted.

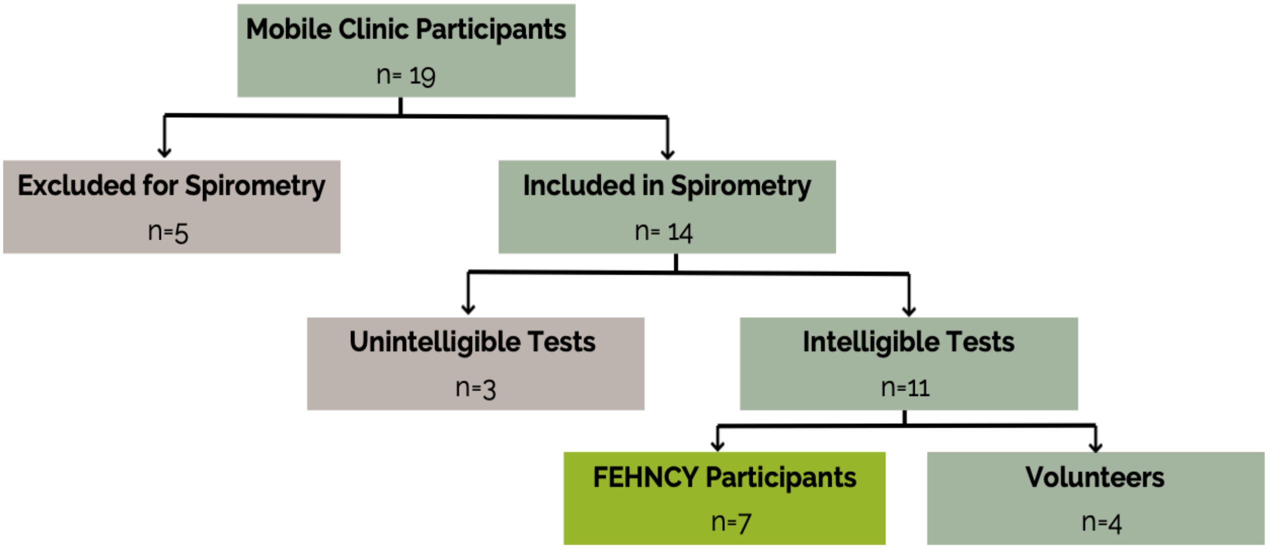


Figure 7. Spirometry participation tree for the mobile clinic. Eleven intelligible spirometry tests were performed.

Table 11. Summary of spirometry results from mobile clinic component (n=11).

SPIROMETRY DESCRIPTIVE RESULTS	MEAN (SD)	MEDIAN	MINIMUM OBSERVED	MAXIMUM OBSERVED
FVC (% Predicted)	105 (18.5)	105	78.0	136
FEV1 (% Predicted)	104 (15.7)	107	78.0	133
MEF25-75 (% Predicted)	105 (22.0)	110	55.0	129

DISCUSSION

Indoor Particulate Matter

Few studies to date have sought to characterize the relationships between indoor air quality, housing conditions, and health risks in First Nations communities. However, this study's indoor air quality measurements are consistent with the few previous studies comparing IAQ levels in FN households with recommended levels and nationally representative averages. In general, particulate matter values in Kanesatake were elevated compared to levels recommended by both Health Canada and the WHO, and ventilation was considered poor in at least one-third of households. Indoor: outdoor ratios for particulates were elevated, suggesting predominantly indoor sources, including smoking, which was significantly associated with indoor particulate concentrations. Relative humidity levels were markedly elevated compared to previous studies in First Nations communities, as was the frequency of past reported flooding. Indoor relative humidity was significantly associated with reduced ventilation, emphasizing the importance of ventilation in controlling humidity. While the direct health effects of indoor relative humidity are not clear, higher humidity can be conducive to the growth of pathogenic biological contaminants. Weak positive relationships were also observed between indoor CO_2 and temperature. This observation may be due to overcrowding, whereby a higher density of people in one space can lead to both increased collective body heat and exhaled CO_2 volumes. Lower household ventilation may also subsequently prevent heated air from circulating out of the house. Higher temperatures are also known to be related to higher relative humidity, which may explain the relationship observed in this study. Higher temperatures can result in higher evaporation rates, and warmer air is capable of holding a greater volume of moisture due to expansion. This is an important relationship to consider in households with flooding concerns such as those in Kanesatake, where there may be more standing water on the floor or around appliances.

The PM results of this study mainly parallel similar studies concerning air quality in First Nations, Inuit, and Métis communities. In a 2022 study by Kovesi et al., the mean indoor $PM_{2.5}$ level across four Ontario First Nations was 17.1 µg/m^3, with 53% of households exceeding the recommended limit for indoor CO_2 (>1000 ppm). However, in contrast to the study by Kovesi et al., where wood stove use was likely an important driver of indoor $PM_{2.5}$, wood stove use was uncommon in Kanesatake. Similarly, Weichenthal et al. (2013) found indoor $PM_{2.5}$ and PM_{10} levels in a sample of households in a Manitoba FN to be several times higher than those found in residential homes in Canada and North America. A similar pattern was observed in the present study, wherein 39% of households exceeded the WHO recommended 24hr guidelines for exposure to $PM_{2.5}$. It must be noted that the presence of smoking occupants is accepted as a strong predictor for indoor PM values both in First Nations and the general population. The elevated prevalence of smoking in First Nations (Lemstra et al., 2011) was considered a possible contributor to the higher PM values observed in the present study. Indeed, mean $PM_{2.5}$ levels in Kanesatake were more than four times higher in smoking households than in non-smoking households (51.8 µg/m^3 and 12.7 µg/m^3, respectively), and the stepwise regression model selected smoking as a significant predictor of indoor PM levels. Health Canada has reported similar patterns in smoking prevalence and indoor PM in studies conducted across various Canadian cities, with the mean national $PM_{2.5}$ level reported as <35 µg/m^3 in smoking homes and <15 µg/m^3 in non-smoking homes. Additionally, the mean peak PM levels in Kanesatake were highly elevated, measuring 258 µg/m^3 (+/- 247). Upon analysis of continuous monitoring data from the AQ Eggs, the PM levels in several households appeared to follow a cyclic daily pattern in concentration fluctuations, with peak daily concentrations occurring in the mornings and evenings for many households and low concentrations consistent throughout the daytime. These patterns suggested that the observed indoor PM values could be attributed to daily occupancy patterns, with houshold occupancy higher in the mornings and evenings. Tahmasebi et al. (2021) recently observed that indoor PM fluctuations correspond with evening cooking activities and evening rush hours in urban London, UK households. Similarly, in a prediction model recently developed by Samek et al. (2017), daily fluctuations in outdoor $PM_{2.5}$ and occupant activities were established as important contributors to the changes in the PM environment. In the present study, three of the households with excessively high PM levels showed this cyclic pattern in PM levels across both deployment periods. All three of these households contained a smoking adult, and these acute rises in indoor PM levels may have been attributed to indoor smoking activity. One of these households also reported daily woodstove use, which may have also contributed to the sudden increased indoor PM rise. Previous studies concerning Indigenous populations have supported the association between woodstove use and indoor PM (Singleton et al., 2016, Kovesi et al., 2022). While the questionnaire administered in this study did not record the time of day at which various activities took place in the household, future studies in this area may benefit from collecting this information to provide more accurate details regarding the sources of indoor PM. This study focused on analysis of $PM_{2.5}$ and PM_{10}, while $PM_{1.0}$ was not analyzed in as much detail. The upper respiratory effects of PM_{10} are well-characterized, and $PM_{2.5}$ is also well-studied due to its ability to penetrate the alveolar barrier to enter the bloodstream. While by definition, $PM_{2.5}$ also includes smaller $PM_{1.0}$, the pathophysiology and health effects of $PM_{1.0}$ are less characterized in the literature; therefore this study chose to focus primarily on the two larger classified particle groups.

Household Characteristics

The household questionnaire results from this study are consistent with previous surveys highlighting household conditions as a priority concern in First Nations. In this study, over one-quarter of houses were reported to need major repairs; this is higher than the proportion reported for FN houses in the 2016 Census (Statistics Canada, 2017). The primary household concerns reported by occupants were mould frequency, dampness, and elevated relative humidity values. The community's proximity to a large body of water (the Ottawa River), compounded with the lack of a working sump pump in most houses and a history of important flooding events in the region (Fedosieieva, 2019), may have been related to the high frequency of leaks, flooding, and subsequent dampness inside houses. These factors may have also contributed to the high relative humidity observed across households, as dwellings near bodies of water tend to exhibit higher indoor relative humidity values. The lack of reported HRVs in most homes is also concerning, given the evidence linking HRVs as impactful interventions for reducing poor IAQ and indoor air-related respiratory illness. In the two households with working HRVs, there were no exceedances for any air quality parameters when comparing observed levels to recommended values.

Furthermore, one of these two households with a reported working HRV was also a household in which one guardian smoked, and the mean $PM_{2.5}$ level across its exposure period remained at 16.1 $\mu g/m^3$. This level is relatively low compared to the mean $PM_{2.5}$ levels in smoking homes in Kanesatake (51.8 $\mu g/m^3$), which further supports the evidence that HRVs can significantly improve IAQ and effectively minimize health risks. Indeed, several studies have examined the effectiveness of air purification measures and other ventilation interventions on the concentrations of indoor air contaminants, both in First Nations and in urban centres. Weichenthal et al. (2013) showed that the presence of an air filter was associated with a mean 37.1 $\mu g/m^3$ decrease in $PM_{2.5}$ levels in a randomized, double-blind crossover study in a Manitoba First Nation. These results corresponded with a mean 217 mL increase in FEV1 in household occupants. A study conducted in a Montreal daycare showed that the presence of a mechanical ventilation system was significantly correlated with lower formaldehyde levels, supporting evidence that indoor ventilation systems may also be critical interventions in minimizing VOC exposure to children (St-Jean et al., 2012). While the present study was not an interventional study, all results were communicated back to households along with suggestions for improving air quality. These measures included accessible interventions such as installing an HRV or air purifier and recommendations that smoking only take place outdoors. However, there is a growing body of evidence to suggest that HRVs and air purifiers alone are inadequate interventions for the improvement of air quality indoors (Walker et al., 2022). Instead, these interventions should be compounded with behavioural changes, such as location and frequency of smoking. This integrated and holistic approach to improving air quality is important to consider when communicating results back to the community. It highlights the value of community-led strategies for improving air quality in ways that are both culturally meaningful and sustainable for community members.

Volatile Organic Compounds

Concentrations of several VOCs exceeded mean values in the CHMS, although they were not over guideline recommendations. Source profiles of the VOCs detected at high frequencies in Kanesatake suggest that occupant and household activity were important sources of VOCs in this sample. Camphene was the only naturally occurring compound of the ten most abundant VOCs observed. Tobacco-related VOCs, including benzene, toluene, ethylbenzene, xylenes, and styrene, were all detected in at least 78.6% of households, with the four BTEX compounds detected at a frequency of 100%. Other common sources of BTEX include vehicle exhaust, indoor gasoline or fuel storage, and the regular use of household products such as paints and candles.

Similarly, Decamethylcyclopentasiloxane and octamethylcyclotetrasiloxane, often referred to as D5 and D4, respectively, are anthropogenic VOCs commonly used in personal care products (PCPs) such as antiperspirants and sun blocks. The dominance of these VOCs in sample households suggests that household activities and occupant behaviour were important determinants of VOCs in these households. The frequency detection results of this study are consistent with the results of Singleton et al.'s study of VOC levels in the homes of Alaska Native children, which found BTEX compounds to be present in all participating households at relatively high levels (2016). It is also well-established that high temperatures may contribute to the off-gassing of VOCs in the household; as such, the elevated levels of BTEX, limonene, D4, and D5 may be related to the fact that several measurements were taken in the heat of the summer months. Additionally, most household occupants (66%) reported having used chemicals indoors within the two weeks before filling out the questionnaire. Several factors may have contributed to shaping the VOC profiles across households. Given these elevated concentration trends observed in several key VOCs, it was surprising to find lower aldehyde levels in Kanesatake compared to the general Canadian population. Common household aldehyde sources include renovation materials such as lacquers, varnishes, and finishes (Won et al., 2013); lower aldehyde levels may thus be related to a lower rate of maintenance and renovation activities in Kanesatake households than in the general population. The data collection methodology for the VOCs in the present study was adapted directly from the CHMS to ensure the comparability between CHMS and FEHNCY. Therefore, although the sample size difference is significant between the CHMS and the Kanesatake pilot, the use of a standardized methodology nevertheless supports their comparability.

Respiratory Health Outcomes

Although respiratory morbidity was not a primary outcome in this study, the spirometry clinic results allowed for the broad characterization of respiratory health in participating children. The FEV1 and FVC levels were within the normal range for all children with one exception. This child (age 11) was referred for a non-urgent follow-up by the study's clinical respirologist due to mild airflow limitation (FEV1 = 78%, FVC = 90%). Interestingly, this participant's household was one of the three households referred for a second air quality Egg deployment due to excessively high PM readings. The household in which this child lived had a mean $PM_{2.5}$ value of 105.3 $\mu g/m^3$ and a mean carbon dioxide level of 1290 ppm. These levels remained consistently high during the second deployment. Additional risk factors were the presence of a smoking adult in the household and proximity to dusty roads, as reported by the household occupants. Although statistical analyses of spirometry outcomes in relation to IAQ were hindered by the very small sample size, it is worth noting the importance of these predictors as potential general risks to children's respiratory health. Evidence of airflow obstruction in FN children has been associated with such risk factors in the past (Sin et al., 2004); however, associations between IAP exposure and spirometry results have been widely studied. Li et al. (2020) found that a 1 μg/kg increase in an average daily dose of $PM_{2.5}$ was associated with a 7.7 mL decrease in children's forced expiratory volume in one second (FEV1) and a 10.5 mL decrease in forced vital capacity (FVC) in a city in northwestern China. Similar results have been reported by other studies in studies conducted in the United States and Portugal (Xu et al. 2020, Isiugo et al. 2019, Martins et al. 2012). Although the sample size was small for this pilot clinic, these data will be integrated into a broader, cross-Nation dataset once several communities have participated in the study. These data will thus contribute to future understandings of the relationship between indoor air quality and respiratory morbidity in First Nations children.

LIMITATIONS

There were several limitations to this study. Due to the pilot nature of this study and the geographical and travel restraints introduced by COVID-19, the results were only collected from one participating community that was not randomly selected, thus presenting a selection bias. In recognizing the heterogeneity of First Nations' experiences with air quality and housing, it must be acknowledged that the external validity of this research is weak. The household participation rate was 57.4%, and the final sample size was only 31% of the original target size. While this participation rate was lower than the initial target rate of 80%, this result may be attributed to several possible factors, including the historical legacy of mistrust between Indigenous communities and researchers and the realities of conducting research during a global pandemic. Indeed, the recruitment period began only three months after the COVID-19 outbreak, and household occupants may have declined participation due to being focused on pandemic management. It is also possible that the multi-component, months-long project design was too large of a commitment to some eligible households. Although participants may decline participation in any component, this option may need to be communicated more effectively in future communities. While there were indeed some difficulties in recruiting participants, the complex nature of data collection and household time commitment must be acknowledged. The small sample size limits the statistical power of the presented analyses, particularly when determining interrelationships between IAQ factors and between IAQ factors and health outcomes. This was particularly true of the VOC detectors, which were only deployed in 14 households. In the original recruitment model, up to 20 VOC monitors were meant to be deployed in a random selection of recruited households. This would have resulted in VOC readings from 20% of the original target 100 households. However, due to the low participation rate and small sample size, VOC tubes were only deployed in 14 randomly-selected households. As it is challenging to predict participation rates for Indigenous environmental health research, it is recommended that in future FEHNCY studies, VOC detectors are deployed in the first 20 participating households. Despite the small sample sizes, once additional communities have enrolled and participated in the broader FEHNCY study, these data will be integrated into a more extensive knowledge and analysis framework. The disparity of time between the household air quality measurements and mobile clinic participation (maximum of 8 months) also limits the associative power of results from the mobile clinic with the indoor air and housing environment to which participating children were exposed. The very small sample size of the mobile clinic participants further limits the power of these relationships.

Additionally, IAQ measurements were taken over 8 months, and this timeframe spanned seasons and major temperature fluctuations. Seasonal variation in occupant behaviour and baseline IAQ values may have influenced the observed results. Finally, the methodology, instrumentation, and reporting methods for indoor air quality parameters are not standardized across regions or research bodies. Several differing methodologies are used across studies to collect AQ data, limiting the opportunity for cross-study comparisons. This is particularly true of $PM_{2.5}$ and PM_{10}, which can be measured using a variety of non-standardized gravimetric and photometric methods. Furthermore, the AQ Eggs used in this study were selected on the basis of user friendliness, but were not research-grade monitors. As such, they did not have internal relative humidity-correcting algorithms for the PM measurements. The relative humidity correction factor applied in this study introduces an extra measure of uncertainty. Additionally, household observations were not made by trained housing inspectors. Although housing inspections by occupants have been used in previous studies, inspections by a trained inspector can provide more detailed and accurate information on indoor environmental quality. Several measures were taken in this study to minimize differences in methods and increase the capacity for comparability by aligning AQ instrumentation and methods with those used in the CHMS whenever possible.

CONCLUSION AND IMPACT

In general, exceedance percentages were notably high for several air contaminants in Kanesatake homes in comparison to recommended values set by national and international governing bodies. Exceedances were particularly notable for PM, relative humidity, and carbon dioxide. BTEX compounds in Kanesatake all showed higher geometric mean values than those collected by the CHMS cycle 3. However, aldehyde concentrations were consistently lower in Kanesatake than in housholds in the general Canadian population. Households often lacked adequate ventilation and lacked dehumidification means. Flooding indoors was an important concern to the community, and was common across participating households. Smoking indoors was a strong predictor of indoor PM.

This was the first study to conduct an indoor air evaluation of First Nations households strictly using remote data collection methods. This study was a critical step toward improving data sovereignty and building community capacity in Indigenous communities by equipping community members with the tools and training required to conduct all data collection independently. This is a crucial step in decolonizing research practices and respecting Indigenous communities' autonomy and traditional knowledge. Additionally, by piloting a protocol for physically distanced, remote IAQ data collection, this study was an important methodological tool for future IAQ studies conducted under travel restrictions, both within and outside of the FEHNCY project.

As a pilot study for the 10-year pan-Canadian FEHNCY project, lessons learned from this work will be considered going forward with the project. This pilot work highlighted key IAQ areas to analyze for consolidation in future FEHNCY studies (e.g. aldehyde level disparities, elevated relative humidity) and areas where intergenerational capacity-building and integrated knowledge translation can be prioritized in reporting data back to communities. Significantly, this pilot study contributed to filling critical knowledge gaps on indoor air quality in First Nations and will help to guide communities and policy-makers in developing programming and public health interventions. By prioritizing community engagement and an IHP lens at all steps of the research process, this pilot fostered a tradition of intergenerational capacity-building that will be carried forth by the FEHNCY study over the next several years.

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CHAPTER 3 | MANUSCRIPT 2

ASSESSING THE FEASIBILITY OF USING REMOTE CBPR METHODS FOR AIR QUALITY AND HOUSING RESEARCH: EXPERIENCES & LESSONS LEARNED

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Research Manuscript

ABSTRACT

Background: Community-based participatory research (CBPR) is emerging as a powerful tool for conducting air quality research, particularly among vulnerable communities. In Canada, CBPR is common practice for conducting health promotion research with Indigenous communities.

Objectives: To assess the feasibility of adapting CBPR methods to a remote setting and reflect on lessons learned in implementing CBPR for air quality and environmental health research during the COVID-19 pandemic.

Methods: Researchers from the Food, Environment, Health & Nutrition of First Nations Children and Youth (FEHNCY) study developed community partnerships with one First Nation. Community researchers (CRs) were hired and trained to facilitate all data collection, including recruitment, air quality measurements, and survey administration in all participants. A virtual community engagement framework was developed and implemented in collaboration with community leaders.

Results/Lessons Learned: Results and lessons learned were categorized into two themes, namely (1) CR experiences and in data collection processes and (2) Data collection outcomes. Lessons learned include the need for an extended and realistic timeline, ensuring at least two CRs are hired, and adapting device deployment methods to minimize inadvertent attrition due to monitor loss.

Conclusions: The results of this study support the feasibility of using virtually-adapted CBPR for conducting air quality research with First Nations communities. Important adaptations should be considered when extending this framework to other Indigenous communities.

INTRODUCTION

Community-Based Participatory Research (CBPR) for environmental health is a powerful framework for addressing health disparities through a solution-based lens, particularly among vulnerable communities. CBPR is an accepted and recommended approach for conducting research with Indigenous communities, where a legacy of exploitative research and mistreatment of communities by academic institutions has led to a culture of mistrust (Schnarch, 2004). CBPR promotes Indigenous sovereignty and self-determination by incorporating communities' desires, needs, and concerns into the research process from conception through data collection, analysis, interpretation of results, and dissemination of results and recommendations to community. Particularly in the context of air quality research, where monitors are becoming increasingly user-friendly and available at lower costs, CBPR presents an excellent framework for addressing air quality, respiratory, and related housing concerns in ways that recognize differences in individual experiences. In addition, traditional IAQ research is particularly sensitive and intrusive, as it has often involved external researchers entering the home and taking measurements around occupants' private space. In 2015, the Agency for Toxic Substances and Diseases Registry (ATSDR) suggested that CBPR was in fact necessary to better understand and address environmental determinants of health and address disparities in the context of pulmonary health (Rohlman et al., 2015). The effectiveness of incorporating researchers from the community itself to conduct data collection and communicate with stakeholders has also been widely supported in the literature (Cidro et al. 2017, Commodore et al. 2017, Collier et al. 2015). CBPR is common practice when conducting health research with First Nations communities in Canada, and experiences with First Nations-centred CBPR have been documented in several studies (Chan et al. 2021, Naqshbandi et al. 2011, Ritchie et al. 2013, Tobias et al. 2013). Intensive community engagement is a critical part of the CBPR process, however in-person engagement activities may not always be possible. For instance, the present study was conducted during the COVID-19 pandemic, at a time when travel restrictions and public health measures limited the capacity for in-person engagement and CBPR work. Although study activities could have been suspended until in-person work could be resumed, the participating FN had a desire to commence data collection. As such, adapting CBPR to a remote (i.e. virtual) setting in this context is important to respecting the needs of communities and striking a balance between the feasibility of methods and community agency. For the purposes of this research, “remote research” is defined as CBPR research that does not involve external researchers visiting the community through the duration of data collection, and instead applies virtual data collection methods. To our knowledge, no studies have been conducted using an entirely remote CBPR framework for collecting knowledge on air quality and housing conditions in First Nations communities. The primary objective of this report is to assess the feasibility of conducting entirely remote air quality research in a FN community using a CBPR framework. The secondary objective of this work was to outline the lessons learned in developing and implementing this framework as a pilot study for a multi-year research project involving First Nations communities from across Canada.

METHODOLOGY

Phase 1: Building Relationship with Community

This study was initiated by first defining shared principles, values, and objectives in collaboration with community leaders from the Kanesatake FN advisory circle, along with the Assembly of First Nations and university partners. Once initial goals and objectives had been discussed, the FEHNCY team worked with community leaders to facilitate relationship building within the community for engagement purposes. The initial engagement period included virtual meetings and youth engagement activities to share information about the study. French and English radio announcements, social media competitions, and brochures were used to deliver integrated information about the study objectives and ways in which the project was designed to promote Indigenous health and wellbeing. Community Researchers (CRs) were hired during this period and were involved in all engagement activities. An opening ceremony for the study was held virtually in Spring 2021 by Kanesatake and FEHNCY leadership. Virtual community engagement and awareness-building activities continued to be held throughout the course of data collection.

Phase 2: Creating Remote Collaborative Framework for Data Collection Approach

In the early stages of this study, all original data collection procedures were adapted for COVID-19 public health measures. Several elements of the original protocol were adjusted to ensure minimal health risk to participating individuals, CRs, and FEHNCY team members. These adjustments are outlined below.

Housing Questionnaire Development

The household questionnaire was adapted in consultation with the Assembly of First Nations housing unit and was pilot tested with FEHNCY team members and CRs to ensure comprehensibility and relevance to the community. While the original research protocol involved an in-person visit from a community household inspector, in the adapted procedures, household occupants completed the questionnaire over the phone with the trained CR. All household data were recorded in real-time using field tablets, and results were stored on a safely secured online cloud. This method allowed for CRs to collect housing data in a COVID-safe setting.

Monitor Selection

The selection of appropriate air quality monitors was carried out by an interdisciplinary team of air quality experts, clinicians, and Kanesatake community leadership. This study sought to measure the levels of indoor particulate matter, volatile organic compounds, CO_2, temperature, relative humidity, and radon indoors. An important goal of the overarching study is to compare air quality and housing characteristics across First Nations to those of the general Canadian home. As such, certain monitors, such as the VOC tubes and radon detectors, were selected based upon their previous use in Health Canada studies. Originally, it was determined that particulate matter, CO_2, relative humidity, and temperature would be measured using YesAir! monitors. However, upon consultation with community leadership, these monitors were replaced by the more user-friendly AQ Eggs. These Eggs were selected due to their ease of installment and real-time access to data readings; this promoted community capacity-building while allowing for CRs to walk participants through the deployment process from a remote location (i.e. through video conferencing or phone call).

Air Quality Deployment Procedures

The remote data collection framework was co-conceived by Kanesatake community leadership, AFN representatives, and the FEHNCY team. Various options for COVID-19-safe data collection procedures were discussed over several virtual meetings, and a final protocol was agreed upon and obtained ethical approval. This protocol involved several COVID-19-pragmatic steps that also promoted capacity-building by allowing household occupants to operate their own air quality monitors without the constant supervision of a CR. Sanitation protocols were incorporated into the protocol at each stage of data handling.

Phase 3: Determining Outcomes of Interest

In order to assess the feasibility of this adapted framework, several outcomes were recorded throughout the process. Outcomes were broken down into three themes, specifically (i) CR hiring, training, and experiences, (ii) Participation, completion outcomes, and (iii) Logistical outcomes.

RESULTS

Community Researcher Hiring and Training Outcomes

CR leadership throughout the study was critical to centralizing community experiences and promoting capacity-building. One CR was hired in January 2021, and two full-day training sessions were conducted over Zoom video-conferencing in March 2021. Training sessions were attended by FEHNCY team members and the CR. Several multimedia resources were used throughout the training sessions to promote integrated CR and team learning. These resources included narrated videos, booklets, and hands-on training materials delivered to the community and were developed through iterative feedback from the Kanesatake Band Council and FEHNCY advisory circle. The videos were viewed by the CR before and after training sessions, and the CR demonstrated an effective understanding of all study SOPs after the sessions were completed. Two follow-up sessions had been scheduled in case additional training was required, but the CR reported feeling confident in their understanding of the data collection procedures. The CR requested additional copies of the training booklets to provide to household participants to further promote capacity-building within the community. In August 2021, a second CR was hired at the request of the original CR. Reasons for enlisting a second CR included (i) division of eligibility screening time (ii) division of travel time to visit households to monitor deployment and pickup.

Participation and Completion Outcomes

Data collection outcomes were assessed by recording participation, completion, and attrition rates for each component of the study (**Table 12)**. The contact rate for households eligible for the air quality and housing component was 67.5%, and the household participation rate was 61.1%. The completion rate for houses enrolled into the study was 94% (n=31 out of n=33 enrolled houses). Completion rate was defined to include households that had completed (i) air quality monitoring for all deployed devices (AQ Egg, VOC Monitor, and radon monitors), and (ii) the full household questionnaire. The completion rate for individual air quality monitors was 96.8% for the AQ Eggs, and 100% for the VOC monitors. The completion rate for radon detectors was 77.4%. Upon consultation with the CRs, it was determined that the loss of radon detectors in all cases was not attributed to participant error or attrition but rather a methodological issue whereby radon monitors were either misplaced or accidentally removed over the 3–6-month deployment period. During the deployment period, the AQ monitor in one household malfunctioned, and in the absence of backup monitors, this household could not complete the AQ data collection. During the mobile clinic data collection period in May 2022, an AQ Egg was redeployed in this household. Data from this exposure period was incorporated into the final AQ dataset. The retention rate of participants for the mobile clinic was 45.1%, and the proportion of original participants from the household component that completed the spirometry measurements was 22.6%.

Table 12. Data collection and participation outcomes in Kanesatake.

KEY OUTCOME	RATE
Eligible household contact rate	67.5% (n=57)_
Participation rate	57.4% (n=31)
Completion rate for housing questionnaire	100% (n=31)
Completion rate for air quality monitors	100% (n=31) AQ Eggs 100% (n=31) VOC monitors 77.4% (n=23) Radon detectors
Retention rate for mobile clinic participation	45.1% (n=14)

Logistical Outcomes

Several logistical outcomes were recorded over the duration of the study. From a timeline perspective, data collection took place over eight months as opposed to the original two-month target. The data collection process accelerated once the second CR was hired and trained. For device logistics, there were few technical challenges related to AQ Eggs and VOC monitors while in the field. All AQ monitors were returned in excellent working condition, and although one monitor was missing a power plug, there were no inventory discrepancies due to shipping or handling for the AQ Eggs. Loss of radon monitors was considered an important logistical challenge. Only 32 radon monitors were retrieved from households; this was a significant inventory discrepancy.

DISCUSSION

Theme 1: CR Experiences, Outcomes and Lessons Learned

The CRs hired in Kanesatake expressed a deep dedication to and enthusiasm for working with community participants. The commitment of CRs to study objectives and the principles of collaborative research was critical to the progress and success of this work. Two important sub-themes that emerged when assessing CR experiences and the feasibility of remote research in this context were (i) the role of CRs in raising community-specific questions and concerns over the course of data collection, which involved direct, real-time feedback, and (ii) the importance of maintaining a flexible timeline to ensure CR comfort and confidence.

Sub-theme 1: Community-Specific Questions

In a typical CBPR framework, the in-person involvement of the external study team is important to ensuring community voices and feedback are heard and incorporated into the study objectives. Due to the nature of remote research, external study members could not visit Kanesatake during the air quality data collection period. As such, CRs played a critical role in communicating participants' and community member's questions and concerns throughout the data collection period. One example in this study was some occupants' concerns about their proximity to the community dumpsite and possible air contaminant exposure from waste facility activities. To address this need, the outdoor air quality monitor was deployed for a more extended period of time close to the dumpsite as a means of better-characterizing air quality in this location.

Additionally, during the mobile clinic phase in May 2022, study protocols ensured that families in proximity to the dumpsite were informed of the biometric measurement component of the study and were invited to participate. Although many of these families were not official participants in the study, it was important that these concerns were validated and incorporated into the project goals. A critical consideration and lesson learned was ensuring CRs had access to real-time feedback channels (i.e. regular, virtual meetings with the study team) to enact necessary adaptations promptly. This is an important consideration given the differences in experience, customs, and attitudes to environmental research between First Nations communities. Methodologies that are well-adapted to some communities may not work as effectively in others. Access to real-time feedback from CRs will be critical to identifying and mediating those differences.

Sub-theme 2: Importance of Timeline Flexibility

The CRS strongly emphasized the importance of making participants feel comfortable and the meaningful relationships built through listening. This method of rapport-building and taking the time to build strong, trustful relationships was considered central to the project's success. This may have contributed to data collection in Kanesatake lasting longer than the original two-month target and is an important reminder of maintaining timeline flexibility. Only one CR was initially hired and trained for the project, as it was believed that one CR would be able to carry out all air quality data collection procedures. However, data collection with one CR was slower than expected due to the time taken to build meaningful relationships through listening. Other reasons included the limited capacity for one person to carry out various research activities, as well as COVID-19 slowdowns. In August 2021, a second CR was hired. This significantly accelerated the data collection process while maintaining the ability to prioritize the time taken to build rapport with participants, as CRs could better divide tasks. This observation aligns with Laveaux and Christopher's principles for conducting CBPR with Indigenous communities (2009). They identify planning for extended timelines as an expected and important consideration in such settings.

Theme 2: Data Collection Outcomes and Lessons Learned

Data collection outcomes showed a high participation retention rate throughout the study, with 100% of enrolled households completing the housing questionnaire and multi-day monitoring by the AQ Egg and VOC monitors. The high retention rate may demonstrate participant interest and investment in their results and supports the feasibility of using this remote framework. However, the loss of radon detectors throughout the data collection was concerning. Due to the extended length of time of deployment for radon monitors, it is important in future that measures are taken to minimize monitor loss. Upon consultation with CRs and household members, it was determined that adding a FEHNCY sticker or double-sided tape to the bottom of the radon detectors may decrease rates of monitor loss in future. Although retention rates were high once participation had been established, the household participation rate was 66.1%. This low household participation rate may be attributed to many factors, including COVID-19-related hesitancies and the historical culture of mistrust for researchers. However, it must be noted that the lack of physical research team presence in the community may have also played a role in lower participation rates. Although remote engagement activities were held throughout data collection, the inability to build relationships in person was a particular barrier. In future, it will be important to extend the scope of remote engagement activities to increase study awareness and build relationships with children and youth.

LIMITATIONS

There were notable limitations to using remote-adapted CBPR to collect air quality data in Kanesatake. One limitation of this remote approach is the introduction of self-reporting bias for the household questionnaire. These self-reporting methods were also not validated against standardized housing inspections. However, several other studies have used occupant-based surveys for IAQ research in Indigenous communities (Larcombe et al., 2011, Kirychuk et al., 2022). Indeed, deploying air quality monitors in one's home may also lead to altered behaviour during the data collection period (such as changes in indoor smoking activity). In CBPR, these reporting biases are well-acknowledged, and it is important to maintain a balance between data integrity and community agency in defining data collection procedures. Regarding monitor use, it must be noted that the AQ Egg monitors were not validated against research-grade monitors used in previous similar studies. These monitors were selected based on their ease of use and feasibility for conducting remote CBPR.

Kanesatake represents just one English-speaking community of hundreds of First Nations in Canada. It is important to recognize that all communities have distinct cultural values, customs, and historical traumas associated with research. Technological barriers may also limit the feasibility of remote CBPR in some communities. Access to internet services and computers may be limited in some First Nations communities, rendering applying these methods difficult. Therefore, the methods assessed in this study may not be applicable to other communities or must retain some flexibility to adapt to different settings.

CONCLUSIONS

Overall, using remote-adapted CBPR for collecting air quality data in Kanesatake was feasible, with some important considerations and adaptations. Maintaining a flexible timeline and including at least two CRs on the research team was critical to building trustworthy relationships with participating households and ensuring CR comfort and efficiency throughout the data collection process. The participant retention rates were very high. However, participation rates were relatively low, possibly attributable to several factors. Expanding the scope of remote community engagement activities to reach parents, children, and youth better may assist in future recruitment efforts. Importantly, this study was a pilot for the long-term FEHNCY project, which will engage multiple First Nations over several years. This work thus provided a critical foundation for determining best practices for conducting CBPR within the FEHNCY framework and highlighted important lessons to be carried forward in the coming years.

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CHAPTER 4 | REFLECTIONS AND CONCLUSIONS

REFLECTIONS & LIMITATIONS

While the reality of conducting this thesis work during the COVID-19 pandemic was unexpected and, at times, challenging, many important lessons were learned. As a pilot study for the multi-year FEHNCY project, the results and experiences of this work will be useful in guiding this project in years to come.

While several lessons can be learned from this pilot work, there were also limitations to this study. The participating community of Kanesatake was not randomly selected, as COVID-19 travel restraints limited the geographical scope of the pilot work. This community volunteered for participation, thus introducing a selection bias. The small sample size (*n*= 31) and moderate-to-low household participation rate certainly limits the statistical power of the presented analyses as well as the generalizability of the study's results. This is particularly true of the relationships between IAQ variables themselves and IAQ variables and health outcomes. The associative power of the spirometry results is also reduced by the length of time (up to 8 months) between the IAQ measurements and the pulmonary function tests. The very small sample size for VOC results (*n*=14) greatly limits the power of these specific analyses. However, after the enrolment and participation of additional communities in the FEHNCY study, these data may be integrated into a broader, cross-Nation knowledge framework. The absence of a standard for methodology, instrumentation, and reporting methods for IAQ variables also introduces a limitation. The heterogeneous nature of IAQ measurement practices, both nationally and internationally, presents a challenge when comparing AQ results between studies. Another important limitation concerns the application of self-reporting methods for the household questionnaires. Self-reporting bias or the adjustment of occupant behaviour during the deployment period again limits the validity of the results. Finally, this was a cross-sectional study conducted in a single English-speaking FN located close to both Montreal and Ottawa. It is important to acknowledge that First Nations have distinct cultural values, customs, knowledge frameworks, traditions, and historical experiences associated with research. While certain methods may have worked well in Kanesatake, these same methods may not be applicable or compatible with other First Nations.

Lessons Learned and Benefits to Future Communities

There are several areas in which the experiences and lessons learned from this thesis work will benefit future FEHNCY studies. Many of these lessons learned were derived through discussions with CRs and community leadership, and are described hereafter.

Community Engagement

The positive response of Kanesatake community members to both virtual and in-person engagement activities supports the importance of researchers' active involvement in building community rapport. Successful engagement activities in Kanesatake included a virtual photography competition and an in-person barbecue at the local high school. While COVID-19 limited the extent to which in-person activities could take place in Kanesatake, in future communities, a variety of activities, both in-person and virtual, will be prioritized as central to building community trust and interest in the study. These events will not only engage adults and elders, but also children and youth in ways that are accessible, interesting, and community-oriented. An important lesson learned regarding community engagement is the timing surrounding the engagement period. Granted, COVID-19 barriers limited capacity for community engagement both on the researchers' and the community's part in Kanesatake, in future, community engagement should begin several weeks prior to study enrolment. Launching earlier and more frequent engagement activities will help to increase community awareness of the study objectives and methods, while allowing ample time to ask questions and build relationships with the researchers.

Study Participation

Expanding the scope of community engagement to include earlier and more frequent activities will aim to increase study participation. A higher number of community engagement activities involving schools, sports teams, or other youth-centric spaces should be conducted in future communities. This is especially relevant to small communities such as Kanesatake, or communities in which the population does not contain a high proportion of children and youth.

Personnel & Community Researchers

A strength of this study was the study team's cohesiveness and ability to work together under unexpected circumstances while adapting to change. In future communities, this strength will allow the study to respond to community needs effectively and collectively. However, in future it will be important to hire at least two CRs per community in order to (1) effectively distribute the data collection responsibilities and (2) assist with the coordination of engagement activities. This will aim to shorten the length of the data collection period, and will minimize the potential of community members losing interest or engagement due to a longer data collection process. This may also reduce the amount of time between the IAQ measurements and spirometry tests, thereby increasing the associative power between these two measurements.

Air Quality Instruments

The high IAQ completion rates for most air quality measurements supports the use of the AQ Egg and VOC monitor in future studies. The simplicity of use of both monitors will support both community capacity-building and CR-directed data collection in the future. One important recommendation is that CRs ensure that AQ Eggs are functioning properly during the deployment set-up, and before beginning the 5-day monitoring period. In the case that a monitor is not functioning, the CR should have extra monitors to provide to occupants. Critically, a method for preventing radon detector loss must be developed; this may include marking detectors with a sticker or adhering them to their surface with double-sided tape. This was a critical lesson learned, as radon is a key indoor air contaminant and it is important that representative data be collected for this variable. Another important lesson concerned the household questionnaire length; although this questionnaire was designed to collect thorough data on the household conditions, this approach increased participants' time commitment. It was proposed that in future, the household questionnaire be reduced in length and question depth in order to reduce any unnecessary time burden on participants.

Communication of Results to Community

The communication of results back to the community members will take place formally after the submission of this thesis. Kanesatake leadership was heavily involved in determining which variables held meaning to the community and were to be reported back to individual occupants. Leadership was also involved in developing protocols for addressing concerning IAQ conditions. The extensive communication between Kanesatake leadership and researchers was a strength of this study. This relationship created a basis of trust that prioritized Indigenous self-determination and cultural agency – values that will be carried forward to future communities.

CONCLUSIONS

Air quality and respiratory morbidity remain seriously understudied topics in the context of First Nations, Inuit, and Métis children's health. The results of this study are consistent with the small body of evidence that highlights IAQ and housing conditions as critical determinants of respiratory health in FN children. Key indoor air pollutants noted at high levels in this study were $PM_{2.5}$, PM_{10}, and BTEX VOCs; the importance of improving household conditions was also highlighted by the results of the housing questionnaire. This study will contribute to the growing body of evidence guiding community-led interventions and public health measures to promote air quality and health. Interventions such as installing ventilators, dehumidifiers, and flood/leak mitigation systems are important considerations for moving forward with collaborative policy decisions. Importantly, this thesis work reflected the successful implementation of CBPR methods for the collection of environmental health data in a FN community. In centering the experiences of community members and leadership as primary stakeholders, this research promotes integrated knowledge translation and self-determinism. Undoubtedly, the ongoing impacts of colonialism and assimilation continue to threaten the health of FN children, and there is much work to be done in improving the indoor air environments of FN children and youth. In focusing on action-based improvements and meaningful research outcomes informed by communities, these changes can be made in powerful ways. In the words of the AFN, "our actions today will determine the quality of air for the next seven generations".

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SUPPLEMENTARY FIGURES AND TABLES

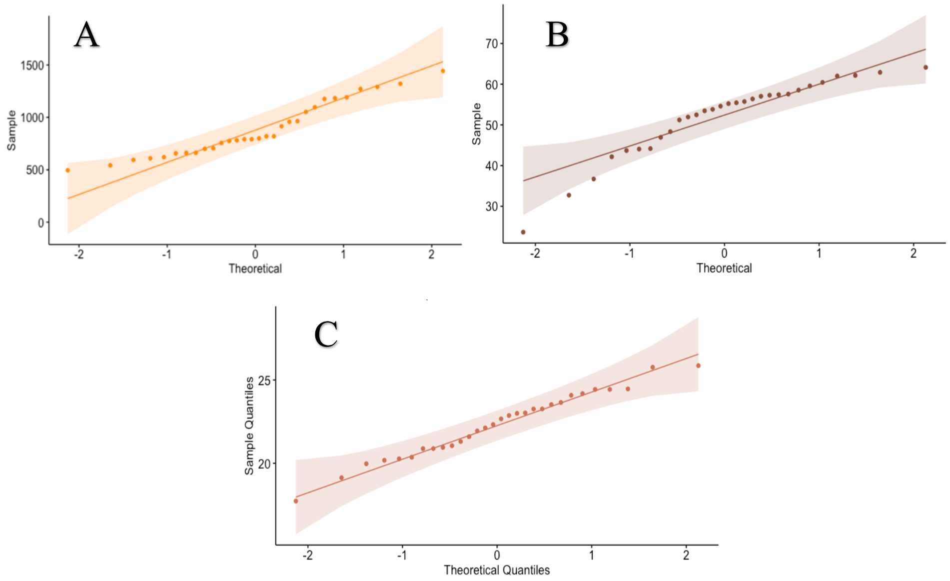

Figure S1. Quantile-Quantile Plots for IAQ Variables to Assess for Skewness. (A) Ventilation, (B) Relative Humidity, (C) Temperatures (n=30)

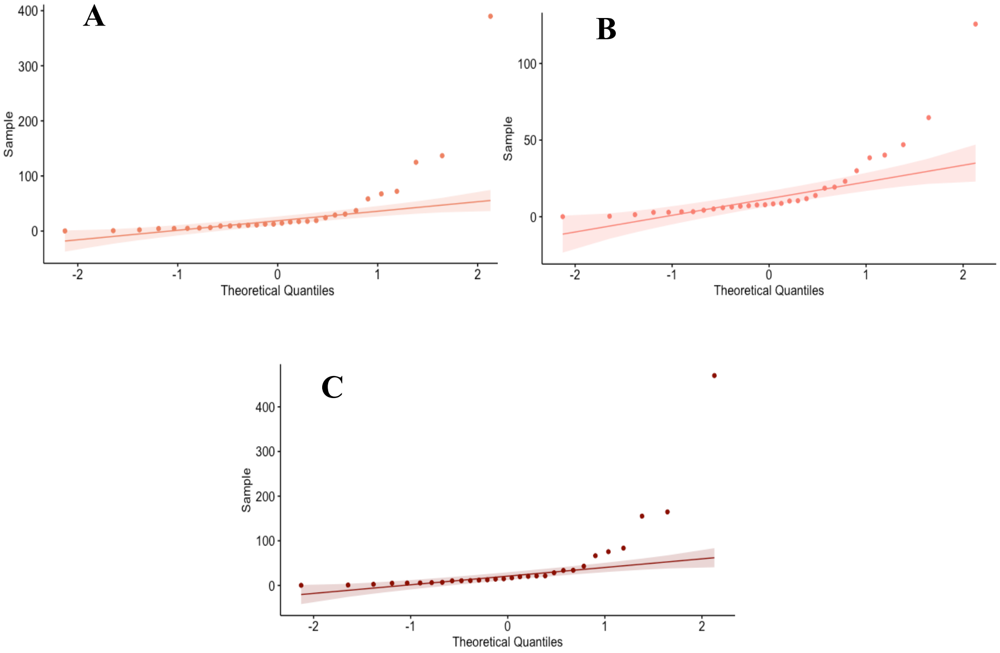

Figure S2. Quantile-Quantile Plots for Particulate Matter Variables to Assess for Skewness. (A) $PM_{2.5}$, (B) $PM_{1.0}$, (C) PM_{10}

Table S1. Skewness and Shapiro-Wilk Tests for Normality. Variables with significant skewness were identified as requiring transformation (log-transformation for right-skewed data; sqrt transformation for left-skewed).

Shapiro-Wilk Normality Test				
Variable	**Shapiro-Wilk**	**Shapiro-Wilk *p-value***	**Distribution**	**Transformation Required**
PM$_{2.5}$ (μg/m^3)	0.488	2.77 e-09*	Highly Right-Skewed	Yes
PM$_{10}$ (μg/m^3)	0.479	2.24 e-09*	Highly Right-Skewed	Yes
PM$_{1.0}$ (μg/m^3)	0.629	1.20 e-07*	Highly Right-Skewed	Yes
CO_2 (ppm)	0.940	8.31 e-02	Slightly Right-Skewed	No
Relative humidity (%)	0.892	4.54 e-03*	Highly Left-Skewed	Yes
Temperature (˚C)	0.982	0.865	Normal	No