Developing an Indoor Air Quality Vulnerability Scale: The Case of Alaska

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Research Problem

Poor indoor air quality (IAQ), evidenced by pollutants such as particulate matter ($PM_{2.5}$), carbon monoxide (CO), volatile organic compounds (VOCs), and allergens, poses serious health risks and varies across locations (Millan et al., 2022; Mujan et al., 2021; Singleton et al., 2018). IAQ vulnerability refers to the exposure or risk of indoor pollutants and the difficulty of households to avoid or adapt to the consequences associated with the exposure (Forbes-Mewett & Nguyen-Trung, 2020; Adger, 2006). In the U.S., marginalized communities such as Alaska Native (AN) populations are disproportionately affected due to factors like mold, inadequate ventilation, housing deterioration, woodstove heating, road dust, overcrowding, and unacceptable humidity levels (Miller et al., 2013; Wilson et al., 2016; Ware et al., 2013; Fleisch et al., 2020; Edwin & e Mölders, 2020; Singleton et al., 2016). These challenges exacerbate health outcomes, including respiratory illness, heart disease, and cancer, particularly among vulnerable groups like children and seniors. Thus, understanding the factors determining IAQ vulnerability in Alaska Native (AN) communities is critical for targeted interventions. However, the complexity of IAQ vulnerability remains poorly understood due to significant measurement challenges.

Research on Indoor Air Quality (IAQ) in Alaska Native communities often focuses on technical indicators like PM2.5, CO2, and VOCs. However, challenges like the high logistics cost, technical expertise for calibrating and maintaining sensors, participant compliance issues, and concerns about privacy, trust, and energy demands make comprehensive home monitoring technically complex and financially burdensome, particularly in remote or resource-limited communities. Given the limitations of objective measurement, researchers have used subjective tools like perception scales and surveys such as the Building Assessment Survey and Evaluation (BASE), the Center for Built Environment (CBE) survey, and the Indoor Environmental Quality (IEQ) survey. These surveys are fundamentally unreliable as they assess IAQ through single-item or binary measures like occupant satisfaction, comfort, or performance. Since IAQ is influenced by

factors like pollutant exposure and housing conditions, single-item or binary measures cannot accurately capture this complexity. Moreover, these existing tools are primarily designed for office and institutional environments, with minimal applicability to residential settings since complex activities like cooking, smoking, and heating practices, which substantially impact air quality, are not captured in these tools. Therefore, developing a multidimensional, perception-based tool tailored explicitly to residential IAQ measurement is crucial. Such an instrument could provide a reliable, valid methodology for gathering robust IAQ data, addressing the current research gap, and potentially improving understanding of residential air quality vulnerabilities. Toward this goal, the study addresses the question, *"What is a reliable and valid scale for measuring IAQ vulnerability?"*

Research Methodology

Initial Scale Development

The initial scale items were developed by synthesizing insights from existing interviews (*n=30*) and a comprehensive literature review of peer-reviewed journal articles investigating IAQ issues in AN communities or Alaska to identify key indicators of IAQ vulnerability. Peer-reviewed journal articles were obtained from the Google Scholar Database. Inclusion criteria included articles that contained terms such as *"IAQ and respiratory health," "IAQ vulnerability," "IAQ exposure or risk," "effects of IAQ on children/elders," "environmental/geographic conditions", "Indoor mold pollution", "indoor mold exposure", "indoor air quality dampness and mold", "PM2.5 exposure in homes", "indoor PM2.5 pollution and health effects" and "Indoor Air Quality"* in their title or Abstract. The review focused on identifying the causes and consequences of poor IAQ since the paper intends to capture all the aspects of IAQ vulnerability. 39 studies were identified after the search. The first screening identified ten studies that were not US-based or peer-reviewed articles, resulting in 29 studies. The final screening removed four studies that were not Alaska-based. The final sample included 25 Journal articles published between 2005 and 2024. Four vulnerability indicators were identified from the qualitative data and literature review, including *pollutant exposure, housing conditions, health and well-being risk, and mitigation factors*. Scale items were generated based on conceptual definitions to ensure content validity, reflecting how well the scale represents the concepts (Bohrnstedt, 1970). In Table 1, **Indicator 1,** *Pollutant Exposure,* measures how pollutant concentrations and duration of exposure to weather

conditions impact IAQ. **Indicator 2,** *Housing Conditions*, measures whether housing conditions such as inadequate ventilation, structural damage, age of home, and overcrowding increase vulnerability. **Indicator 3**, *IAQ Mitigation*, measures the factors hindering households' ability to adapt or address IAQ challenges. **Indicator 4,** *Health and Well-being Risk*, measures people's physical and psychological risks due to poor IAQ. Consequently, 24 items were selected based on the literature, and 17 items were added by the authors based on field data. These additional items highlight the role of individual behaviors like using air quality monitors, air purifiers, or cleaning practices, and psychological impacts of pollutants lacking in existing tools.

Table 1: Initial IAQ Vulnerability Scale Items

Indicators	Construct	Scale Items	Source
Pollutant Exposure	Pollutant concentration 1	I previously had mold or mildew in my home.	Millan et al., 2022; Singleton et al., 2016
	Pollutant concentration 2	I often notice dust accumulation on surfaces in my home.	Schenck et al., 2010
	Pollutant concentration 3	I am exposed to tobacco smoke or other substances in my home.	Hwang et al., 2011
	Pollutant concentration 4	I often burn scented candles and incense or use air fresheners in my home.	Edwin & Mölders, 2020; Simpson et al., 2010
	Pollutant concentration 5	I use chemical cleaning products in my home.	Miller, 2013
	Pollutant concentration 6	I have pets and pet dander in my home.	Author construct
	Heating practice 1	I use a wood stove in my home.	Semmens et al., 2015; Ware et al., 2013
	Heating practice 2	I use a fuel-powered boiler or furnace in my home.	Bell et al., 2005; Johnson et al., 2002
	Heating practice 3	I use space heaters or portable gas heaters in my home.	Author construct
	Climate risks 1	I boil water to increase the humidity level in my home.	Wind et al., 2004
	Infrastructural impact 1	I smell or see smoke from nearby facilities or factories.	Bell et al., 2005
Housing Conditions	Inadequate ventilation 1	My home does not have enough windows.	Author construct
	Inadequate ventilation 2	My home does not have exhaust fans in the kitchen or bathroom.	Ferguson et al., 2020
	Inadequate ventilation 3	My house is airtight with inadequate or no ventilation system.	Stevens et al., 2020; Ferguson et al., 2020
	Heating/Cooling 1	My heating system is outdated or faulty.	Author construct
	Heating/Cooling 2	My cooling system is outdated or faulty.	Author construct

	Structural damage 1	I have an old house with structural damage (e.g., leaks, faulty ventilation systems, inefficient insulation, etc.)	Holden et al., 2023; Miller et al., 2013
	Structural damage 2	I hardly maintain my home.	Author construct
	Space limitation 1	My home is overcrowded with limited space.	Singleton et al., 2005; Lewis et al., 2004; Miller, 2013
IAQ Mitigation	Equipment use 1	I often use an air purifier in my home.	Author construct
	Equipment use 2	I often use an air quality monitor in my home.	Author construct
	Equipment use 3	I often use a dehumidifier in my home.	Author construct
	Ventilation practices 1	I often open windows to increase airflow in my home.	Stevens et al., 2020; Millan et al., 2022
	Ventilation practices 2	I often use ventilation systems (e.g. vents and fans).	Stevens et al., 2020; Millan et al., 2022
	Cleaning Practices 1	I often clean surfaces in my home.	Author construct
	Pollutant awareness 1	I am unaware of the sources of mold in my home.	Zhang, 2004; Millan et al., 2022
	Pollutant awareness 2	I am unaware of the sources of carbon monoxide poisoning in my home.	Zhang, 2004; Millan et al., 2022
	Pollutant awareness 3	I am unaware of the sources of particle pollution in my home.	Zhang, 2004; Millan et al., 2022
	Pollutant awareness 4	I am unaware of the sources of VOCs in my home.	Zhang, 2004; Millan et al., 2022
	Pollutant awareness 5	I am unaware of the sources of radon in my home.	Zhang, 2004; Millan et al., 2022
	Pollutant awareness 6	I am unaware of the sources of asbestos in my home.	Zhang, 2004; Millan et al., 2022
	Health risk awareness 1	I am unaware of the health risks of radon.	Author construct
	Health risk awareness 2	I am unaware of the health risks of asbestos.	Author construct
	Health risk awareness 3	I am unaware of the health risks of mold.	Author construct
	Health risk awareness 4	I am unaware of the health risks of carbon monoxide poisoning.	Author construct
	Health risk awareness 5	I am unaware of the health risks of particle pollution.	Author construct
	Health risk awareness 6	I am unaware of the health risks of VOCs.	Author construct
Health and Wellbeing Risk	Health risk 1	I feel there is an increase in respiratory symptoms (e.g., asthma, coughing, wheezing) in my household.	Short et al. 2024; Yang, 2019; Singleton et al. 2018
	Health risk 2	I feel that poor air quality in my home has negatively affected my heart health.	Jang, 2014; Yang, 2019
	Psychological risk 1	I feel anxious or worried about mold growth and mildew in my home.	Author construct
	Psychological risk 2	I feel anxious or worried about the dust in my house.	Author construct

	Psychological risk 3	I feel anxious or worried about not having enough ventilation in my home.	Author construct

Data Collection

Data collection focused on Alaska due to the dire IAQ challenges communities face. Based on the indicators, a survey that includes the scale items and demographic questions was designed. Participants will be asked to respond to 23 of the items on a 5-point Likert scale from "Strongly disagree" to "Strongly agree" and 18 of the items on a Yes/No response. The Center for Survey Statistics and Methodology (CSSM) at Iowa State University will assist in administering the survey electronically to residents in Alaska using Qualtrics. The study will undergo ethical approval from the Alaska Area IRB and ISU IRB before the survey is deployed.

Data Analysis

After the initial data collection across Alaska, the Cronbach's alpha test and Exploratory Factor Analysis (EFA) will be performed to ensure construct reliability and validity respectively. Exploratory Factor Analysis (EFA) aims to identify the number of underlying factors without predetermining specific ones (Bartholomew et al., 2011). This approach will help adjust items across different constructs while remaining guided by theoretical frameworks. Due to the ordinal nature of the data, EFA will be conducted by calculating a polychoric correlation matrix and generating a scree plot to determine the optimal number of latent factors. The factor structure identified in EFA will be confirmed by performing CFA on a different dataset gathered from selected AN communities.

Contributions of Study

The IAQ vulnerability scale is critical for underrepresented communities like Alaska Native communities. The multiple-item scales support robust hypothesis testing and provide a comprehensive framework for understanding interconnected factors that create vulnerability. The scale reflects the complexity of IAQ as a multidimensional concept, offering greater reliability and reducing biases compared to single indicators. By integrating multiple items, the IAQ vulnerability scale enables nuanced insights into the interplay of environmental, housing, and health factors, moving beyond binary assessments. Also, the contextual sensitivity of the scale allows for adaptive

measurement strategies that account for local environmental and cultural conditions, revealing subtle variations in IAQ risks.

Practically, the scale offers targeted, actionable guidance for addressing environmental health disparities in Alaska Native communities. By identifying specific risk factors and vulnerability mechanisms, the scale enables public health officials to design targeted interventions such as prioritizing mold remediation in housing units with the highest risk profiles, developing community-specific ventilation improvement strategies, and allocating resources to areas with the most critical indoor air quality challenges. Additionally, the scale provides a culturally responsive tool that captures localized IAQ nuances, transforming abstract vulnerability concepts into concrete, actionable data. By quantifying complex interactions between housing characteristics, environmental conditions, and community health, the scale creates a direct pathway for translating research insights into practical community-level improvements. Communities can also use data from the scale to seek funding opportunities for housing, pollution control, healthcare needs, and educational campaigns on IAQ mitigation strategies.

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