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# Impact of home remediation and household education on indoor air quality, respiratory visits and symptoms in Alaska Native children

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## ABSTRACT

Alaska Native children experience high rates of lower respiratory tract infections (LRTIs) and lung conditions, which are associated with substandard indoor air quality (IAQ). We conducted an intervention of home remediation and education to assess the impact on IAQ, respiratory symptoms and LRTI visits. We enrolled households of children 1–12 years of age with lung conditions. Home remediation included improving ventilation and replacing leaky woodstoves. We provided education about IAQ and respiratory health. We monitored indoor airborne particles (PM2.5), $CO_2$, relative humidity and volatile organic compounds (VOCs), and interviewed caregivers about children's symptoms before, and for 1 year after intervention. We evaluated the association between children's respiratory visits, symptoms and IAQ indicators using multiple logistic regression. A total of 60 of 63 homes completed the study. VOCs decreased (coefficient = −0.20; p < 0.001); however, PM2.5 (coeff. = −0.010; p = 0.89) did not decrease. Burning wood for heat, VOCs and PM2.5 were associated with respiratory symptoms. After remediation, parents reported decreases in runny nose, cough between colds, wet cough, wheezing with colds, wheezing between colds and school absences. Children had an age-adjusted decrease in LRTI visits (coefficient = −0.33; p = 0.028). Home remediation and education reduced respiratory symptoms, LRTI visits and school absenteeism in children with lung conditions.

## Introduction

Alaska Native children living in rural southwest Alaska experience some of the highest reported rates of hospitalisation from lower respiratory tract infections (LRTIs) [1]. The pneumonia hospitalisation rate for infants from Alaska's southwest Yukon Kuskokwim (YK) Delta region is tenfold higher than for other US infants [1]. Bronchiectasis, a chronic lung sequelae of early and severe pneumonia, has nearly disappeared from the developed world, but is still frequently seen among southwest Alaska Native children [2,3].

Previous research demonstrates that substandard indoor air quality (IAQ) and inadequate housing lead to increased and more severe respiratory disease [4–8]. Inadequate housing conditions in southwest Alaska can negatively affect IAQ [3,9–11]. Household crowding, indoor smoke, lack of piped water and poverty have been independently associated with LRTIs. These

factors are more common in rural southwest Alaska than in the general US population [12–14], and help explain the disparity in LRTIs and chronic lung sequelae in children from this region.

We conducted an intervention in Alaska's rural southwest YK Delta and Bristol Bay regions to evaluate the impact of simple home remediation and household education on the household IAQ and respiratory symptoms in children with chronic lung conditions. We monitored indoor airborne small particulate matter 2.5 microns (PM2.5), carbon dioxide ($CO_2$), relative humidity (RH), temperature and volatile organic compounds (VOCs), and interviewed caregivers about children's respiratory symptoms. We previously reported the baseline study IAQ and household characteristics [15]. In this paper, we describe the impact of home remediation on IAQ, and on respiratory symptoms and LRTI visits in household children.

## Methods

### Setting and approvals

Approximately 31,000 primarily Alaska Native people reside in Alaska's rural YK Delta (58,000 square miles) and Bristol Bay (46,714 square miles) regions. Communities in these regions are accessible year round only by aircraft, and seasonally by boat or snowmobile. YK Health Corporation (YKHC) and Bristol Bay Area Health Corporation (BBAHC) are tribal organisations providing comprehensive health care delivery and environmental health services and use electronic health record systems.

We recruited Alaska Native households during a 4-year period (2011–2015) to participate in a 1 year prospective study to evaluate IAQ, respiratory symptoms and respiratory visits before, and during the year after, home remediation. The study was approved by the Alaska Area and the Centers for Disease Control and Prevention's (CDC) Institutional Review Boards, the Alaska Native Tribal Health Consortium (ANTHC), and the YKHC and BBAHC tribal organisations. A tribal representative in the participating community provided written support prior to contact with participants. Household adults provided written consent prior to this participation.

### Recruitment

We selected 63 households with a high-risk child for the study. High-risk children were defined as children 1–12 years of age with lung disease (e.g. asthma) who had, in the previous 12 months, been treated in an outpatient setting at least 4 times, or hospitalised at least once for respiratory problems.

### Data collection

We collected data on housing conditions, IAQ and respiratory health of high-risk children and other household children [15]. We created a home assessment tool specific to rural Alaska, and gathered data on occupancy level, ventilation, in-home pollution sources and resident behaviours including smoking, woodstove use, cooking, household activities and hobbies, during home walk-through and interviews [15].

We monitored indoor PM2.5, $CO_2$, % RH, temperature (degrees Fahrenheit) and VOCs in the living room for 24–96 consecutive hours three times: 2 weeks before, and then 2 weeks and 12 months after home remediations. Child health outcomes were evaluated using caregiver respiratory health questionnaires conducted twice before the intervention and at 2 weeks, 3 months and 12 months after the intervention. Each questionnaire covered respiratory symptoms and missed school in the previous 2-week period, using questions from a respiratory questionnaire created by the American Thoracic Society for epidemiologic studies [16].

Visit data were downloaded from the regional and referral hospital electronic medical record systems. Adult (age≥18 years) household members were included in the study in years 3 and 4. Adult visit data were not available for one of the villages.

### Interventions

Home remediation included installing passive vents, range hoods and or bathroom fans; replacing old leaky woodstoves with more efficient, EPA-certified models; fixing or replacing oil-fired furnaces and addressing moisture issues. Building professionals from tribal regional housing authorities completed the home remediation. Environmental health professionals provided home-based education using discussions and informational pamphlets. Target behaviours addressed in the education included burning dry wood, proper use of home ventilation systems, gasoline storage, using best household cleaning practices and smoking outside the home. Three months after interventions, a respiratory therapist or case manager made an in-home visit to provide education on respiratory triggers, asthma medication use and medication compliance. Activity logs of IAQ-related behaviours were completed daily by study personnel during the air sampling periods.

### Data analysis

Air quality data were assessed with a random effects model accounting for household. VOC was also reported as BTEX (benzene, toluene, ethylbenzene, o-xylene and m,p-xylene). PM2.5 and $CO_2$ were log-transformed for analysis. VOCs, BTEX and % BTEX were presented as summary measurements collected over the 4 days. RH was calculated as the mean; $CO_2$ and PM2.5 were calculated as geometric mean concentrations (GMC) from multiple measurements for the 4-day reporting period.

Associations between possibly confounding factors and air quality measurements were performed with each individual factor and IAQ measure (except the time period variable that has two levels). Multivariable analyses include all factors with a given IAQ measure.

Interval questionnaire data were analysed with a logit model with a random effect for person.

Analyses of numbers of visits in the pre and post intervention years were done with a matched t-test for means and Sign Rank test for medians. Pre- and post-periods were defined as the 12 months prior to intervention and 12 months after construction was complete; however, year 1 villages had only the same 8 calendar months available pre and post. Health facility visit rates were assessed with a Poisson regression model with a random effect for person. Health facility visits were reviewed and categorised by diagnosis (*International Classification of Diseases (ICD)*, 9th and 10th Revisions), and medications prescribed. "LRTI" included pneumonia, bronchiolitis, chronic lung disease, bronchiectasis and bronchitis. "Acute respiratory infections (ARI)" included LRTI plus croup, upper respiratory infection, otitis and reactive air disease/asthma. "Any asthma medication" included albuterol as well as corticosteroid inhalers and oral corticosteroids. All analyses were conducted in Stata 10 and p-values <0.05 were considered significant.

## Results

### Interventions

63 homes in 8 communities were enrolled and 60 homes participated in the intervention study. 1-year follow-up data were available for 52 homes. Remediation in homes included ventilation improvements (installing Fresh 80 Passive Air Inlet vents [Therma-Stor, Madison WI.], bathroom fans and/or range hoods) in 59 homes (98%), woodstove replacement in 28 (47%), new oil-fired furnace in 14 (23%) and moisture abatement in 6 (10%).

### Air quality

IAQ measurements showed significant decreases in total VOCs, BTEX and the BTEX/Total VOC ratio over the course of the study (Table 1). PM2.5 did not change significantly over the study period. An average of 22% of PM2.5 readings within a home exceeded 35 $\mu g/m^3$ at both the pre- and 1 year post time points. $CO_2$ levels for study year 1 were higher than the measurement capacity of the monitor (0–2,500 ppm), and could not be recorded. Median $CO_2$ was 1,401 ppm for remaining homes. $CO_2$ did not show a decline over the study period. 65–77% of the average proportion of $CO_2$ readings were above the acceptable indoor air level (>1,000 ppm) during the 3 sampling periods [17]. RH showed a significant increase at 1-year post remediation. At that time an average of 81% of measurements within homes were in the recommended 30–60% range, compared with 63% initially.

Factors associated with adverse IAQ included smoking in the home, use of a woodstove, average number of persons sleeping in the home, outdoor air temperature and absence of piped water in the home (Table 2). The average number of persons sleeping in the household was positively associated with all of the IAQ indicators measured. Smoking and woodstove use were positively associated with PM2.5. The presence of piped water in the home was negatively associated with all of the measures except PM2.5 and RH.

**Table 1.** Indoor air quality measurements pre- and post-remediation in study homes in southwest Alaska, 2011–2016.

| Indoor air measurement | | Baseline | Post remediation** | 1 year after baseline | Random intercept model coeff. for per (p)* |
|---|---|---|---|---|---|
| Total VOCs ($\mu g/m^3$) | GMC (95% CI) | 107 (79, 145) | 94 (74, 121) | 78 (64, 96) | **−0.20 (<0.001)** |
| | Median | 99 | 89 | 61 | |
| BTEX VOCs ($\mu g/m^3$) | GMC (95% CI) | 53 (37, 77) | 49 (36, 66) | 32 (24, 44) | **−0.32 (<0.001)** |
| | Median | 45 | 44 | 29 | |
| BTEX/Total VOC (%) | Mean (95% CI) | 51% (45%, 56%) | 52% (47%, 56%) | 43% (37%, 49%) | **−0.044 (0.001)** |
| | Median | 49% | 50% | 43% | |
| PM2.5 ($\mu g/m^3$) | GMC (95% CI) | 12.0 (9.4, 15.2) | 12.1 (9.2, 15.9) | 12.3 (9.7, 15.6) | −0.010 (0.890) |
| | Median | 18 | 22 | 15 | |
| $CO_2$***(ppm) | GMC (95% CI) | 1379 (1194, 1592) | 1243 (1117, 1384) | 1466 (1248, 1722) | 0.027 (0.288) |
| | Median | 1401 | 1264 | 1418 | |
| RH (%) | Mean (95% CI) | 35.9 (33.0, 38.9) | 34.5 (31.5, 37.6) | 42.7 (39.4, 46.0) | **2.51 (0.001)** |
| | Median | 35.6 | 32.6 | 42.8 | |

* Values are assessed with a linear mixed model (by home) on the log transformed values. Per coded as (1,2,3).
** Post remediation is 1–2 months after baseline.
*** Years 2–4.
The bold values are significant with a p-value <0.05
VOC measurements are one summary over 4 days of collection, PM2.5, $CO_2$ and RH are mean (RH) and GMC (PM2.5, $CO_2$) from multiple measurements over the 4 days. Carbon monoxide was measured in years 2–4. 98% of levels (118/121) were <5 ppm, the remaining 3 levels were all <20 ppm.
VOC: volatile organic compounds; GMC: geometric mean concentration; PM2.5: small airway particles; RH: relative humidity; BTEX: total of benzene, toluene, ethylbenzene, o-xylene and m,p-xylene.

**Table 2.** Coefficients from linear (Ln) models of indoor air quality on time periods after remediation and possible confounding factors in southwest Alaska homes before and after interventions, 2011–2016.

| | | Coefficient (p-value) | | | | | | |
| | | Time period | | | | | | |
| | | 2 | 3 (Period diff) | Smoking | Woodstove use | Avg num slept in HH | Outdoor air temp | Piped water |
|---|---|---|---|---|---|---|---|---|
| Ln(Total VOC) | Univariate | −0.14 | **−0.41 (<0.001)** | −0.036 (0.865) | 0.035 (0.798) | **0.066 (0.014)** | **−0.011 (0.002)** | **−0.930 (<0.001)** |
| | Multivariate | −0.14 | **−0.37 (0.004)** | 0.041 (0.833) | 0.059 (0.638) | **0.055 (0.022)** | −0.005 (0.161) | **−0.837 (<0.001)** |
| Ln(BTEX) | Univariate | −0.11 | **−0.65 (<0.001)** | −0.069 (0.801) | 0.29 (0.101) | **0.088 (0.009)** | **−0.015 (0.001)** | **−1.205 (<0.001)** |
| | Multivariate | −0.11 | **−0.61 (<0.001)** | −0.006 (0.981) | **0.32 (0.037)** | **0.075 (0.012)** | −0.005 (0.245) | **−1.08 (<0.001)** |
| Ln(PM2.5) | Univariate | −0.016 | −0.019 (0.989) | **0.69 (0.003)** | **0.048 (0.001)** | **0.058 (0.034)** | −0.002 (0.562) | 0.016 (0.934) |
| | Multivariate | −0.051 | −0.003 (0.909) | **0.72 (0.001)** | **0.46 (0.002)** | **0.071 (0.006)** | −0.001 (0.774) | 0.043 (0.821) |
| Ln(CO$_2$) | Univariate | −0.078 | **0.061 (0.012)** | −0.008 (0.924) | −0.090 (0.135) | **0.058 (<0.001)** | 0.0004 (0.763) | **−0.344 (0.006)** |
| | Multivariate | −0.095 | **0.109 (<0.001)** | 0.052 (0.474) | −0.048 (0.349) | **0.068 (<0.001)** | 0.0008 (0.556) | **−0.38 (<0.001)** |
| % BTEX | Univariate | 0.006 | **−0.093 (<0.001)** | 0.023 (0.638) | **0.093 (0.002)** | **0.015 (0.008)** | **−0.003 (0.002)** | **−0.140 (<0.001)** |
| | Multivariate | 0.006 | **−0.087 (<0.001)** | −0.019 (0.649) | **0.095 (0.001)** | **0.012 (0.021)** | −0.001 (0.427) | **−0.12 (0.002)** |
| Avg RH | Univariate | −1.14 | **5.67 (<0.001)** | 1.11 (0.691) | **−3.78 (0.003)** | **1.031 (0.003)** | **0.262 (<0.001)** | 1.11 (0.662) |
| | Multivariate | −2.41 | **3.85 (0.001)** | 1.33 (0.544) | −1.85 (0.197) | **1.01 (0.001)** | **0.25 (<0.001)** | −2.79 (0.241) |

Household smoking during the air quality sampling period occurred 12% (18/153 sampling periods) of the time, wood stove use occurred 33% (50/153) of the time and 55% (33/60) of the homes had piped water. The average number of people sleeping in the home was 6.7 and the median outdoor air temperature was 16.4°F (min −10.5°F, max 39.4°F).
The bold values are significant with a p-value <0.05
VOC: volatile organic compounds; PM2.5: small airway particles; RH: relative humidity; BTEX: total of benzene, toluene, ethylbenzene, o-xylene and m,p-xylene; Avg Num slept in HH: average number of people sleeping in the home.

## Respiratory health

The 63 households contained 214 participating children who ranged in age from 1 month to 13 years of age (mean 5.5 years). The 72 high-risk children were significantly younger (mean 4.2 years) than the 142 other household children (mean 6.2 years, p < 0.001). The number of participating children per household ranged from 1 to 7, with a mean of 3.4.

Compared to the baseline period, parents reported a decreased proportion of children with respiratory symptoms (Table 3). After adjusting for age category and season, and using high-risk status as factor, reports of respiratory symptoms in household child decreased after interventions. Significant adjusted decreases were noted for colds or runny nose, cough between colds, wet cough, wheezing with colds, wheezing between colds and need for inhaler or nebuliser. Reported school absenteeism decreased (coefficient 0.19, p < 0.001). Adults in households, adjusted for age, sex, season, also reported a decrease in wet cough (coefficient 0.39, p = 0.020) (Data not shown).

## Outpatient clinic visits for respiratory infection

We evaluated outpatient medical visits in the year pre- and post-intervention for household children and adults. Overall, there was a decrease in all visits, ARI visits, LRTI visits for all household children, but not adults (Table 4). Visits with a prescription for albuterol or any asthma treatment increased in children after the 3-month respiratory education visit. Clinic visit rates were inversely associated with child age. When adjusted for age increase over time, the decrease in all clinic visits and LRTI visits remained significant for high-

**Table 3.** Parent-reported respiratory symptoms on an interval questionnaire adjusted for age category and season; high-risk status as factor, in Alaska study homes, before and after household interventions, 2011–2016. No interactions between high-risk and post-intervention are significant.

| | Pre | | Post | | | |
| | Initial visit (n = 204) | Pre-intervention (n = 203) | 2-weeks post (n = 198) | 3-months post (n = 174) | 1-year post (n = 155) | Post Odds Ratio (p-value) |
|---|---|---|---|---|---|---|
| Cold or runny nose? | 118 (58%) | 111 (55%) | 83 (42%) | 80 (46%) | 64 (41%) | **0.53 (0.003)** |
| Any cough between colds? | 74 (36%) | 86 (43%) | 60 (30%) | 58/173 (34%) | 39/154 (25%) | **0.57 (0.004)** |
| Any wet cough? | 51/202 (25%) | 42/202 (21%) | 33/197 (17% | 45/173 (20%) | 19/152 (13%) | **0.61 (0.037)** |
| Any wheezing or whistling? | 36/202 (18%) | 31/202 (15%) | 26 (12%) | 29/172 (17%) | 12/152 (8%) | 0.60 (0.057) |
| Any wheezing between colds? | 22 (11%) | 10 (5%) | 3 (2%) | 5 (3%) | 6 (4%) | **0.40 (0.020)** |
| Any wheezing attack? | 7 (3%) | 11 (5%) | 3 (2%) | 5 (3%) | 6 (4%) | 0.73 (0.497) |
| Needed inhaler or nebuliser? | 42/203 (21%) | 35/202 (17%) | 23/197 (12%) | 32/172 (19%) | 15/153 (10%) | **0.58 (0.049)** |
| Any missed school for illness? | 23/138 (17%) | 19/127 (15%) | 13/132 (10%) | 6/67 (9%) | 3/112 (3%) | **0.19 (<0.001)** |

The bold values are significant with a p-value <0.05

**Table 4.** Matched comparison of healthcare visits in all household children and adults, in Alaska study homes before and after household interventions, 2011–2016.

| | | Children | | | Adults* | | |
|---|---|---|---|---|---|---|---|
| | | Pre** | Post | p-value*** | Pre | Post | p-value |
| N | | 182 | | | 79 | | |
| All Visits | Mean (±SE)**** | 13.6 (±0.77) | 11.2 (±0.64) | **<0.001** | 10.5 (±1.24) | 11.3 (±1.57) | 0.578 |
| | Median | 11.5 | 9 | **<0.001** | 7 | 8 | 0.833 |
| ARI | Mean (±SE) | 6.99 (±0.57) | 5.24 (±0.43) | **<0.001** | 2.41 (±0.37) | 2.25 (±0.36) | 0.574 |
| | Median | 4 | 3.5 | **<0.001** | 1 | 1 | 0.532 |
| LRTI | Mean (±SE) | 1.91 (±0.25) | 1.36 (±0.19) | **0.007** | 0.72 (±0.19) | 0.49 (±0.15) | 0.095 |
| | Median | 0 | 0 | **0.013** | 0 | 0 | 0.119 |
| Antibiotic | Mean (±SE) | 4.05 (±0.31) | 4.01 (±0.31) | 0.902 | 2.71 (±0.46) | 3.06 (±0.41) | 0.448 |
| | Median | 3 | 3 | 0.611 | 1 | 2 | 0.093 |
| Albuterol | Mean (±SE) | 1.84 (±0.21) | 2.64 (±0.30) | **0.007** | 1.90 (±0.46) | 1.75 (±0.41) | 0.763 |
| | Median | 1 | 1 | 0.075 | 0 | 0 | 0.827 |
| Asthma Rx | Mean (±SE) | 2.02 (±0.23) | 2.88 (±0.31) | **0.003** | 2.13 (±0.48) | 1.91 (±0.42) | 0.672 |
| | Median | 1 | 1 | **0.032** | 0 | 0 | 0.578 |

\* Adult data are available for 3 villages from years 3 and 4.
\*\* Pre and Post periods are 1 year in length except for year 1 villages where the period is 8 months.
\*\*\* p-values are calculated with a matched t-test (mean) and signrank test (median).
\*\*\*\* SE: Standard error of the mean.
The bold values are significant with a p-value <0.05
ARI: acute respiratory infections; LRTI: lower respiratory tract infections; Rx: prescription.

**Table 5.** Poisson regression of number of visits pre- and post-household interventions, using random effects model with random effect for person, for children in study households, 2011–2016.

| | High-risk children | | Other household children | | All children | |
|---|---|---|---|---|---|---|
| | Coefficient (95% CI) | | Coefficient (95% CI) | | Coefficient (95% CI) | |
| | | Adj* | | Adj* | | Adj* |
| **All Visits** | | | | | | |
| All | **−0.32** | **−0.12** | **−0.20** | 0.03 | **−0.20** | −0.012 |
| | **(−0.40, −0.23)** | **(−0.24, −0.005)** | **(−0.18, −0.02)** | (−0.06, 0.12) | **(−0.26, −0.14)** | (−0.08, 0.06) |
| ARI | **−0.41** | −0.13 | **−0.16** | 0.09 | **−0.29** | 0.02 |
| | **(−0.53, −0.29)** | (−0.29, 0.03) | **(−0.28, −0.04)** | (−0.06, 0.23) | **(−0.37, −0.21)** | (−0.09, 0.13) |
| LRTI | **−0.56** | **−0.32** | −0.02 | 0.67 | **−0.34** | 0.16 |
| | **(−0.78, −0.34)** | **(−0.61, −0.03)** | (−0.28, 0.22) | (0.32, 1.03) | **(−0.50, −0.17)** | (−0.06, 0.39) |
| Antibiotic Rx | **−0.18** | 0.02 | 0.09 | **0.29** | −0.01 | **0.22** |
| | **(−0.35, −0.02)** | (−0.19, 0.23) | (−0.04, 0.23) | **(0.14, 0.44)** | (−0.11, 0.09) | **(0.10, 0.33)** |
| Albuterol Rx | 0.19 | **0.36** | **0.47** | **0.59** | **0.36** | **0.52** |
| | (−0.03, 0.41) | **(0.09, 0.63)** | **(0.29, 0.66)** | **(0.38, 0.81)** | **(0.22, 0.50)** | **(0.35, 0.68)** |
| Asthma Rx | **0.21** | **0.34** | **0.46** | **0.59** | **0.35** | **0.51** |
| | **(0.01, 0.41)** | **(0.09, 0.59)** | **(0.28, 0.64)** | **(0.38, 0.79)** | **(0.22, 0.49)** | **(0.35, 0.66)** |

*Adjusted model includes adjustment for age as three linear splines (<2, 2–3, 4–13 years).
Includes participants available for entire pre and post periods.
The bold values are significant with a p-value <0.05
LRTI: lower respiratory tract infection; ARI: acute respiratory infection; Rx: prescription.

risk children, but not other children or overall (Table 5). After adjustment for age and sex, adult household members had a decrease in LRTI visits (coefficient = −0.44, p = 0.036). Hospitalisations were relatively rare during the study period. The total number of LRTI hospitalisations in the study children decreased from 15 (7 children) pre-intervention hospitalisations to 5 (3 children) post-intervention hospitalisations.

## Discussion

This is the first report of the impact of home remediation and home-based education on IAQ, respiratory symptoms and medical visits in Alaska Native children with chronic lung conditions. Compared with other US homes, these study houses were overcrowded, a high proportion were without running water and heating with woodstove was common [15]. The high-risk children and other household children both had high rates of cough and wheezing and LRTI hospitalisations compared with other US children [15], consistent with effects from similar household exposures. Although, the initial focus of the study was on reducing indoor pollutants due to woodstove use, we found that IAQ was complex and potentially related to several other factors including crowding, reduced ventilation and tobacco smoke, the presence of fuels and fuel storage and use of homes as workshops. Following remediation, there was a decrease in parent-reported child respiratory symptoms

and missed school. After adjusting for age, there was a decrease in all visits and LRTI visits for high-risk children and decrease in LRTI visits in adults.

We showed a significant adjusted decrease in parent-reported child respiratory symptoms (e.g. runny nose, wheeze, cough) and a decrease in parent-reported school absenteeism for respiratory illness. The reduction in upper respiratory tract infections (colds or runny nose) is clinically important, as viral upper respiratory tract infections are the commonest trigger of asthma exacerbations in children [18]. We also demonstrated an age-adjusted decrease of 0.3 LRTI visits per year per child for the high-risk children with chronic lung conditions. Education on clean burning, tobacco use, respiratory medications and household cleaning, as well as home remediation may have contributed to the impact on VOCs and respiratory symptoms. The increase in albuterol prescriptions after respiratory education likely reflects increased family awareness of respiratory morbidity. In a systematic review, Crocker et al. [19] reported that home-based, multi-component interventions addressing multiple triggers with education were the most effective interventions in reducing asthma-related acute care visits, symptoms and school absences in children with asthma. Economic analysis suggested that benefits could match or exceed programme costs [20].

Reduction in LRTI visits in children with chronic lung conditions has potential implications for their future respiratory health. Longitudinal studies show that childhood pneumonia is associated with asthma, and with impaired lung function, which persists into adulthood [21]. The study region has one of the highest LRTI hospitalisation rates in the US [1,22], with median cost of LRTI hospitalisation for respiratory syncytial virus estimated at $22,323 [23]. One out of 63 children in this region develop a chronic lung condition, bronchiectasis, from severe or repeated pneumonias, which can lead to increased morbidity in adulthood [2,24].

In our study, several household factors contributed to indoor air pollutants, including number of persons sleeping in the household, presence of smoker(s) and wood as primary heat source. High concentrations of VOCs and PM2.5 were associated with higher risk for cough between colds; VOCs were also associated with higher risk for wheeze between colds and asthma diagnosis. PM2.5 did not decrease after the intervention; however, our measurement periods were only a few days out of the 1-year post-intervention period. Although early woodstove interventions showed decreases in PM2.5, more recent wood change-out studies have had variable results with many houses not demonstrating significant sustained PM2.5 decreases

[25,26]. The varied PM2.5 response across homes in our studies and others may be due to factors (e.g. household size, household activities, ventilation) other than the introduction of a new woodstove [25,27]. The recent Asthma Randomized Trial of Indoor Wood Smoke study demonstrated that air filtration units were superior (68% decrease) to woodstove change-out (no significant reductions) in reducing PM2.5 in homes; however, their effectiveness in reducing LRTIs is unknown [28].

VOCs were present at detectable levels in all homes and at levels above the minimum risk levels in several homes [15]. Many VOCs are classified as known irritants, and VOC exposure has been associated with the onset and exacerbation of asthma [29]. In our study homes, potential sources for benzene and other VOCs included woodstove and Toyo stove (diesel fuel oil-fired furnace) use, tobacco smoke, fuel, detergents and insecticides, and using homes as workshops for tasks like fixing snowmobile engines. In addition, we found that absence of piped water was associated with higher VOCs. Although this relationship is unexplored, households without piped water may have differences in heating, storage of water and/or cleaning agents that affect IAQ. VOCs were associated with respiratory symptoms (cough, wheeze, asthma) in household children; decrease in VOCs after remediation could have contributed to reduction in cough and wheeze in household children.

Our conclusions are limited by the absence of a placebo arm; however, our conclusions are supported by the high retention of study households and the correlation of parental reports of symptoms with the decline in clinic visits. Rates of wheezing and respiratory infections typically decline with age in young children [30], including children living in the Arctic [31]. We attempted to address this by controlling for age in the multi-variable analysis. A placebo-controlled trial would more definitively determine whether our interventions significantly changed respiratory morbidity in high-risk rural Alaskan children. However, the interventions we introduced would be difficult to establish in a blinded fashion and this was unacceptable to the local tribal organisation. The introduction of multiple interventions, including respiratory (asthma) education, made it impossible to determine which intervention(s) were effective. However, previous environmental intervention studies for asthma have used a similar approach, and as the causes of airway inflammation are multifactorial, it can be argued that a home-based multifaceted approach is needed to improve asthma outcomes [19,32]. We do not know whether results from this study are generalisable to the general population

for this region (e.g. whether households without high-risk children share similar IAQ features as the study households). Monitoring of IAQ and respiratory symptoms was performed only at intervals, and may not accurately reflect the household IAQ or respiratory symptoms of household children during the study period.

## Conclusion

Alaska Native children have markedly elevated rates of respiratory morbidity. In this IAQ intervention in homes of Alaska Native children with chronic lung conditions, we documented high levels of indoor air pollutants (PM2.5 and VOCs) which were associated with respiratory symptoms in household children. Our multicomponent intervention, including home remediation focused on woodstoves and ventilation, coupled with household education, resulted in a decrease in parent-reported respiratory symptoms, school absence and LRTI visits in high-risk children. This type of interventions, including house remediation and respiratory education, could be employed to improve IAQ and result in lasting respiratory health and school success in high-risk children with chronic lung conditions.

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## Disclaimer

The findings and conclusions in this article are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention or the tribal organisations.

## Disclosure statement

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## References

1. Foote EM, Singleton RJ, Holman RC, et al. Lower respiratory tract infection hospitalizations among American Indian/Alaska Native children and the general United States child population. Int J Circumpolar Health. 2015;74:29256. PubMed PMID: 26547082; PubMed Central PMCID: PMC4636865.

2. Singleton R, Morris A, Redding G, et al. Bronchiectasis in Alaska Native children: causes and clinical courses. Pediatr Pulmonol. 2000 Mar;29(3):182–187. PubMed PMID: 10686038.

3. Singleton RJ, Valery PC, Morris P, et al. Indigenous children from three countries with non-cystic fibrosis chronic suppurative lung disease/bronchiectasis. Pediatr Pulmonol. 2014 Feb;49(2):189–200. PubMed PMID: 23401398.

4. Dherani M, Pope D, Mascarenhas M, et al. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bull World Health Organ. 2008 May;86(5):390–398C. PubMed PMID: 18545742; PubMed Central PMCID: PMC2647443.

5. Kovesi T, Creery D, Gilbert NL, et al. Indoor air quality risk factors for severe lower respiratory tract infections in Inuit infants in Baffin Region, Nunavut: a pilot study. Indoor air. 2006 Aug;16(4):266–275. PubMed PMID: 16842607.

6. Morris K, Morgenlander M, Coulehan JL, et al. Wood-burning stoves and lower respiratory tract infection in American Indian children. Am j dis child. 1990 Jan;144 (1):105–108. PubMed PMID: 2294707.

7. Robin LF, Less PS, Winget M, et al. Wood-burning stoves and lower respiratory illness in Navajo children. Pediatr Infect Dis J. 1996;15:859–865.

8. Rehfuess EA, Tzala L, Best N, et al. Solid fuel use and cooking practices as a major risk factor for acute lower respiratory infection mortality among African children. J Epidemiol Comm Hlth. 2009;63:886–892.

9. Hennessy TW, Ritter T, Holman RC, et al. The relationship between in-home water service and the risk of respiratory tract, skin, and gastrointestinal tract infections among rural Alaska Natives. Am J Public Health. 2008;98:1–7.

10. Wiltse N, Madden D, Valentine B, et al. 2014 Alaska Housing Assessment. Alaska Housing Finance Corporation; Cold Climate Housing Research Center: Fairbanks, AK; 2014.

11. Ware D, Lewis J, Hopkins S, et al. Sources and perceptions of indoor and ambient air pollution in rural Alaska.

J Community Health. 2013 Aug;38(4):773–780. PubMed PMID: 23526077; PubMed Central PMCID: PMC3706583.

12. Bulkow LR, Singleton RJ, DeByle C, et al. Risk factors for hospitalization with lower respiratory tract infections in children in rural Alaska. Pediatrics. 2012 May;129(5): e1220–e1227. PubMed PMID: 22508919.

13. Bulkow LR, Singleton RJ, Karron RA, et al. Risk factors for severe respiratory syncytial virus infection among Alaska native children. Pediatrics. 2002 Feb;109(2):210–216. PubMed PMID: 11826197.

14. Wenger JD, Zulz T, Bruden D, et al. Invasive pneumococcal disease in Alaskan children: impact of the seven-valent pneumococcal conjugate vaccine and the role of water supply. Pediatr Infect Dis J. 2010 Mar;29(3):251–256. PubMed PMID: 19952861; eng.

15. Singleton R, Salkoski AJ, Bulkow L, et al. Housing characteristics and indoor air quality in households of Alaska Native children with chronic lung conditions. Indoor air. 2016 Jun 18. PubMed PMID: 27317363. DOI: 10.1111/ina.12315.

16. Ferris BG Epidemiology Standardization Project (American Thoracic Society). Am Rev Respir Dis. 1978 Dec; 118 (6 Pt 2): 1–120. PubMed PMID: 742764.

17. ASHRAE. Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers Inc; 2004. p. 38.

18. Gern JE Virus/allergen interaction in asthma exacerbation. Ann Am Thorac Soc. 2015 Nov;12 Suppl 2:S137–S143. PubMed PMID: 26595729; PubMed Central PMCID: PMCPMC4722838.

19. Crocker DD, Kinyota S, Dumitru GG, et al. Effectiveness of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity: a community guide systematic review. Am J Prev Med. 2011 Aug;41(2 Suppl 1):S5–S32. PubMed PMID: 21767736.

20. Nurmagambetov TA, Barnett SB, Jacob V, et al. Economic value of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity a community guide systematic review. Am J Prev Med. 2011 Aug;41(2 Suppl 1):S33–S47. PubMed PMID: 21767734.

21. Chan JY, Stern DA, Guerra S, et al. Pneumonia in childhood and impaired lung function in adults: a longitudinal study. Pediatrics. 2015 Apr;135(4):607–616. PubMed PMID: 25733757; PubMed Central PMCID: PMCPMC4379462.

22. Karron RA, Singleton RJ, Bulkow L, et al. Severe respiratory syncytial virus disease in Alaska Native children. RSV Alaska Study Group. J Infect Dis. 1999 Jul;180(1):41–49. PubMed PMID: 10353859.

23. Borse RH, Singleton RJ, Bruden DT, et al. The economics of strategies to reduce respiratory syncytial virus hospitalizations in Alaska. J Pediatric Infect Dis Soc. 2014 Sep;3 (3):201–212. PubMed PMID: 26625383.

24. Redding GJ Bronchiectasis in children. Pediatr Clin North Am. 2009 Feb;56(1):157–171, xi. PubMed PMID: 19135586.

25. Noonan CW, Navidi W, Sheppard L, et al. Residential indoor PM2.5 in wood stove homes: follow-up of the Libby changeout program. Indoor air. 2012 Dec;22 (6):492–500. PubMed PMID: 22607315; PubMed Central PMCID: PMC3445774.

26. Ward T, Boulafentis J, Simpson J, et al. Lessons learned from a woodstove changeout on the Nez Perce Reservation. Sci Total Environ. 2011 Jan 15;409(4):664–670. PubMed PMID: 21144555.

27. Semmens EO, Noonan CW, Allen RW, et al. Indoor particulate matter in rural, wood stove heated homes. Environ Res. 2015 Apr;138:93–100. PubMed PMID: 25701812; PubMed Central PMCID: PMC4385435.

28. Ward TJ, Semmens EO, Weiler E, et al. Efficacy of interventions targeting household air pollution from residential wood stoves. J Expo Sci Environ Epidemiol. 2015 Nov 11. PubMed PMID: 26555475. DOI: 10.1038/jes.2015.73

29. Tagiyeva N, Sheikh A Domestic exposure to volatile organic compounds in relation to asthma and allergy in children and adults. Expert Rev Clin Immunol. 2014 Dec;10(12):1611–1639. PubMed PMID: 25399826.

30. Martinez FD, Wright AL, Taussig LM, et al. Asthma and wheezing in the first six years of life. The Group Health Medical Associates. N Engl J Med. 1995 Jan 19;332 (3):133–138. PubMed PMID: 7800004.

31. Kovesi TA, Cao Z, Osborne G, et al. Severe early lower respiratory tract infection is associated with subsequent respiratory morbidity in preschool Inuit children in Nunavut, Canada. J Asthma. 2011 Apr;48(3):241–247. PubMed PMID: 21391880.

32. Morgan WJ, Crain EF, Gruchalla RS, et al. Results of a home-based environmental intervention among urban children with asthma. N Engl J Med. 2004 Sep 9;351 (11):1068–1080. PubMed PMID: 15356304.