*Indoor Air 2009; 19: 489–499*
*www.blackwellpublishing.com/ina*
*Printed in Singapore. All rights reserved*

© *2009 John Wiley & Sons A/S*

**INDOOR AIR**
*doi:10.1111/j.1600-0668.2009.00615.x*

# Heat recovery ventilators prevent respiratory disorders in Inuit children

**Abstract** Inuit infants have high rates of reported hospitalization for respiratory infection, associated with overcrowding and reduced ventilation. We performed a randomized, double-blind, placebo controlled trial to determine whether home heat recovery ventilators (HRV) would improve ventilation and reduce the risk of respiratory illnesses in young Inuit children. Inuit children under 6 years of age living in several communities in Nunavut, Canada were randomized to receive an active or placebo HRV. We monitored respiratory symptoms, health center encounters, and indoor air quality for 6 months. HRVs were placed in 68 homes, and 51 houses could be analyzed. Subjects had a mean age of 26.8 months. Active HRVs brought indoor carbon dioxide concentrations to within recommended concentrations. Relative humidity was also reduced. Use of HRV, compared with placebo, was associated with a progressive fall in the odds ratio for reported wheeze of 12.3% per week (95%CI 1.9–21.6%, $P = 0.022$). Rates of reported rhinitis were significantly lower in the HRV group than the placebo group in month 1 (odds ratio 0.20, 95%CI 0.058–0.69, $P = 0.011$) and in month 4 (odds ratio 0.24, 95%CI 0.054–0.90, $P = 0.035$). There were no significant reductions in the number of health center encounters, and there were no hospitalizations. Use of HRVs was associated with in improvement in air quality and reductions in reported respiratory symptoms in Inuit children.

**T. Kovesi[1], C. Zaloum[2], C. Stocco[3], D. Fugler[4], R. E. Dales[5,6], A. Ni[7], N. Barrowman[7], N. L. Gilbert[8], J. D. Miller[9]**

[1]Department of Paediatrics, Children's Hospital of Eastern Ontario, University of Ottawa, Ottawa, ON, Canada, [2]Sustainable Buildings and Communities, CANMET Energy Technology Centre-Ottawa, Natural Resources Canada, Ottawa, ON, Canada, [3]Air Health Effects Division, Health Canada, Ottawa, ON, Canada, [4]Policy and Research, Canada Mortgage and Housing Corporation, Ottawa, ON, Canada, [5]Department of Medicine, Ottawa Hospital, Ottawa, ON, Canada, [6]Biostatistics and Epidemiology Division, Health Canada, Ottawa, ON, Canada, [7]Children's Hospital of Eastern Ontario Research Institute, Ottawa, ON, Canada, [8]Canadian International Development Agency, Gatineau, QC, Canada, [9]Department of Chemistry, Carleton University, Ottawa, ON, Canada

Key words: Respiratory Tract Infections; Ventilation; Child; Preschool; Inuits; Wheezing; Bronchiolitis; Pneumonia.

T. Kovesi
Paediatric Respirologist
Children's Hospital of Eastern Ontario
401 Smyth Rd.
Ottawa, ON K1H 8L1
Canada
Tel.: 613-737-7600 ext. 2868
Fax: 613-738-4886
e-mail: kovesi@cheo.on.ca

Received for review 20 February 2009. Accepted for publication 27 June 2009.
© Indoor Air (2009)

**Practical Implications**

Reduced ventilation is common in the houses of Inuit children in arctic Canada, and is associated with an increased risk of respiratory infection. Installation of HRV brings indoor carbon dioxide concentration, as a marker of adequate ventilation, to within recommended concentrations, although relative humidity is also reduced. Installation of HRV is associated with improvements in indoor air quality, and a reduced risk of wheezing and rhinitis not associated with cold air exposure in young Inuit children. Further research is required to explore traditional Inuit cultural attitudes about air movement in dwellings.

## Introduction

Inuit infants in Qikiqtaaluk (Baffin) Region, Nunavut, Canada have the highest reported rate of hospitalization for severe respiratory syncytial virus infection in the world (Banerji et al., 2001). High rates have also been reported elsewhere in the arctic, including the Canadian Northwest Territories, Greenland, and Alaska (Karron et al., 1999; Koch et al., 2002; Young et al., 2007). Serious, long-term pulmonary complications may follow these infections, including bronchiectasis and *bronchiolitis obliterans* (Herbert et al., 1977; Singleton et al., 2000). Exposure to indoor tobacco smoke (ETS), a known risk factor for respiratory disorders including wheezing (Li et al., 1999) and rhinitis (Johansson et al., 2008), is extremely common in Nunavut (Kovesi et al., 2007). In addition, we have previously shown that home ventilation was reduced in most houses in Qikiqtaaluk region (Kovesi et al., 2006, 2007). Indoor carbon dioxide ($CO_2$) is an indicator of both overcrowding and reduced ventilation. We subsequently observed that higher indoor concentrations of $CO_2$ were associated with an increased risk of lower respiratory tract infection in several communities in Nunavut (Kovesi et al., 2007). This study was designed to test the hypotheses that the installation of heat recovery ventilators (HRV) would increase home ventilation, which, in turn, would reduce the risk of lower respiratory tract illness in young Inuit children.

## Methodology

### Study design and population

We performed a trial to evaluate the effect of HRVs on the respiratory health of young Inuit children in Qikiqtaaluk Region. To minimize the amount of new ductwork that would be required, we chose four communities with a high proportion of houses heated using ducted heating systems, rather that electric baseboard or hot water radiator systems. In consultation with the Nunavut Housing Corporation, Clyde River, Igloolik, Pangnirtung, and Pond Inlet were therefore selected. We worked with local community groups to inform each hamlet about the study. Local

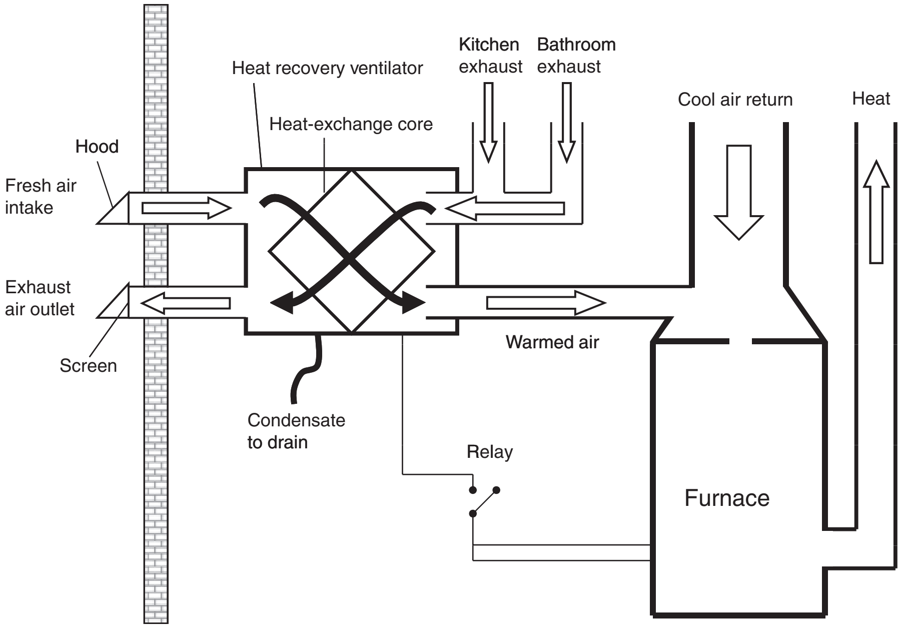

**Fig. 1** Illustration of the connection of a heat recovery ventilator to a furnace in a house with forced-air heating

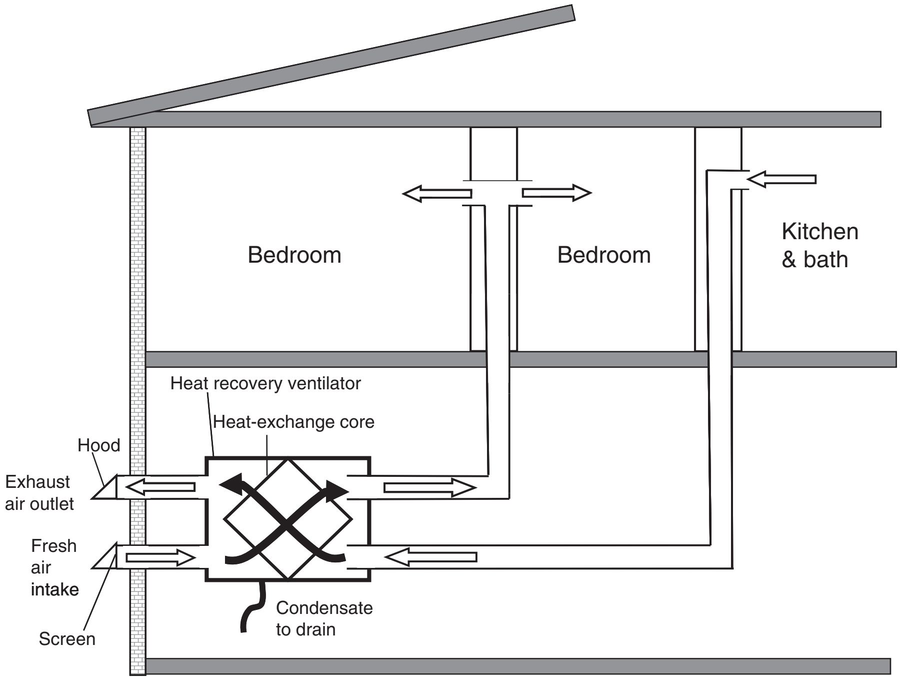

**Fig. 2** Illustration of the connection of a heat recovery ventilator in a typical crawlspace installation, in a home with hydronic or baseboard heating

using a random numbers table. Active and placebo devices were visually and sounded identical, provided similar amounts of air movement, and were installed using identical ducting and outside air vents. Some active units were fitted with a digital hour counter. However, neither this information, nor which units were active or placebos, were relayed by the study engineers (DF and CZ) to the study personnel, research assistants, or occupants during the study.

### Outcome measurements

Occupants initially received the standard American Thoracic Society Children's Respiratory Questionnaire (ATS DLD 78c) (Ferris, 1978). All study families then received brief bi-monthly follow-up questionnaires from October 2007 through March 2008, administered by research assistants hired at each study site. The research assistants were trained by the principal

**Fig. 3** Photograph of a Venmar Constructo 1.0 heat recovery ventilator installed in the furnace room of a study house

investigator (TK). Uniform translation of respiratory symptoms into Inuktitut (Kovesi, 2008) was provided using translators from the Ottawa Health Services Network Inc. (Ottawa, ON, Canada). Follow-up questionnaires were administered by telephone for families who had telephones, and in person for the remaining families. When questionnaires were delayed because of inclement weather, research assistants were instructed to inquire about the child's health since the previous visit. We recorded visits to the community health center for respiratory illnesses or otitis media, and reported episodes of wheezing, cough, and upper respiratory tract infections. Occupant comfort and concerns was evaluated with the questionnaires. We recorded hospitalizations for lower respiratory tract illnesses at the regional hospital, the Baffin Regional Hospital in Iqaluit, Nunavut, and in hospitals outside Nunavut. The follow-up questionnaire was also based on the ATS DLD 78c questionnaire (Ferris, 1978) (Table 1). Reported health care encounters were cross-verified with records at each community health center by a pediatric respirologist (TK). Respiratory tract infections were classified according to the method of Dallaire and coworkers (Dallaire et al., 2004). We have

**Table 1** Questions used for the bi-weekly follow-up health questionnaire, and question number for the analogous question in the ATS DLD-78c survey (Ferris, 1978)

| Question: In the past week (or, since your last interview), has this child had: | Response type | ATS-DLD-78c Question Number |
|---|---|---|
| A cough? | Yes/No | 14A and B |
| Wheezing? (Note: wheezing is a whistling sound coming from the chest) | Yes/No | 17A and B |
| Difficulty breathing? | Yes/No | 18A |
| A runny nose (even when staying inside or at night)? | Yes/No | 16C |
| A sore throat? | Yes/No | 20A |
| A fever? | Yes/No | 20A |
| Chest congestion (or 'a congested chest')? | Yes/No | 15A and B |
| To visit the Nursing Station? | Yes/No | 22 |
| If so, what were you told at the Nursing Station was wrong with this child? | Comment | 22 |
| To be admitted to the Baffin Regional Hospital in Iqaluit? | Yes/No | 21 |
| If so, what were you told at the hospital was wrong with this child? | Comment | 21 |
| To be admitted (and stay) at a hospital outside Nunavut (for example, Ottawa or Montreal)? | Yes/No | 21 |
| If so, what were you told at the hospital was wrong with this child? | Comment | 21 |
| If there have been other medical problems with this child (or other things we should know about this child) since the last interview, please type them in here: | Comment | None |
| If there have been problems with the heating or ventilation system of this house, or other problems with this house since the last interview, please type them in here: | Comment | Not applicable |
| Check if heat recovery ventilator is unplugged? | Yes/No | Not applicable |

previously observed that the great majority of Inuit infants are exposed to ETS, and that the reported number of smokers in the homes of Inuit infants correlated significantly with airborne nicotine concentration (Kovesi et al., 2006, 2007). ETS exposure was assessed in this study by the research assistants during the initial questionnaire (Ferris, 1978).

Indoor air quality measurements were carried out during the middle of the study period, between January and March 2008. Indoor relative humidity, temperature, and $CO_2$ were measured simultaneously over 3–5 days once or twice in each study house with a portable YES 206LH monitor (YES Environment Technologies Inc., Delta, BC, Canada). The monitor logged data every 15 min. It used a non-dispersive infrared technique for the detection of $CO_2$ (YES Environment Technologies Inc, 2003). The monitors were installed in a central area in each house by the research coordinators.

### Statistical analysis

We aimed to select as many eligible houses in the study communities as was feasible, based on time and cost. Outcomes are presented using a conservative intent-to-treat analysis. This included all subjects who had a HRV installed in the home and who agreed to remain in the study for at least one data collection period (e.g. 1 month). Data were analyzed using SPSS version 16 (SPSS Inc., Chicago, IL, USA). Dichotomous variables were analyzed using Fisher's exact test. Normally distributed continuous variables were compared using Student *t*-tests. Non-normally distributed continuous variables were compared using Mann–Whitney rank test. Count variables (e.g. the number of visits to the community health centers) were analyzed using Poisson regression. The odds of reporting symptoms of wheezing, cough, and upper respiratory tract infection in each group were analyzed over time using a logistic marginal model with generalized estimating equations using an exchangeable working correlation matrix. In one case, there were zero events in one cell of the model making it unstable. Empirical logits were therefore used (Agresti, 1991), by introducing a pseudo-subject with a response of 0.5 into each group. To avoid confounding by respondent recall, we decided to consider each measurement as a point-in-time, rather than assuming that each interval assessment accurately described symptoms occurring since the previous assessment. An interim analysis was not conducted.

## Results

Sixty-eight HRVs were installed and 51 were included in the intent-to-treat analysis (Figure 4). Counter data were available for 14 active HRVs. In the houses with valid counter data, the HRVs ran for a median of 3120 h (range 138–6102 h), or a median of 57.8% (range 30–70%) of study period. This is consistent with the units running when the furnace was on, which would be expected to be about 60% of the time. If a run time of 2500 h was selected as evidence that the HRVs were left plugged in for most of the winter, 10/14 (71%) of these HRVs were plugged in for at least 2500 h.

Children included or not included in the intent-to-treat analysis were generally similar, although the children not included tended to be older, and had significantly fewer reported visits to the local health center prior to the study (Table 2). Participants receiving active or placebo HRVs were generally well matched (Tables 3 and 4). Respiratory morbidity was high amongst all subjects. Twenty-one of 68 (30.9%) were reported to have previously had bronchiolitis. Fourteen of 68 (20.6%) were reported to have previously had pneumonia. Sixteen of 68 (23.5%) were reported to have been admitted to the regional hospital in Iqaluit before 2 years of age. None of the children had been admitted to hospitals outside Nunavut for respiratory illness prior to the study. Four of 68 (5.9%) children were reported to have previously had latent tuberculosis, and one was reported to have had active

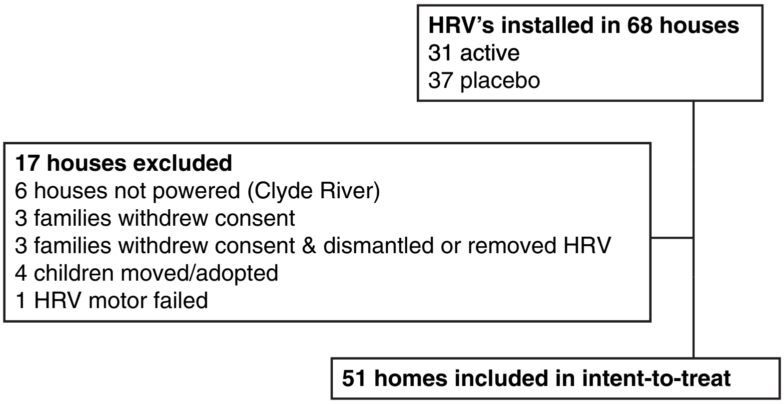

**Fig. 4** Study flow chart (HRV: heat recovery ventilator)

**Table 2** Comparison of baseline health characteristics of subjects included, or not included, in the intent-to-treat group

| Variable | In intent-to-treat group | Not in intent-to to treat group |
|---|---|---|
| Age (months) | 26.8 (15.4) [48] | 34.9 (12.4) [11] |
| Gender (% male) | 32/51 (62.7%) | 8/12 (66.7%) |
| Adopted (%) | 17/51 (33.3%) | 7/17 (41.2%) |
| Reported wheeze with colds prior to study (%) | 19/32 (37.3%) | 5/17 (29.4%) |
| Reported wheeze apart from colds prior to study (%) | 9/51 (17.6%) | 3/17 (17.6%) |
| Reported number of visits to health center before 2 years of age | 3.6 (3.5) [50] | 0.8 (1.3) [17]* |
| Reported number of admissions to regional hospital before 2 years of age | 0.3 (0.6) [51] | 0.4 (0.7) [17] |

Continuous variables are presented as mean (s.d.) [*n*].
*$P < 0.001$.

**Table 3** Comparison of baseline health characteristics of subjects with active or placebo heat recovery ventilators

| Variable | Active heat recovery ventilator | Placebo heat recovery ventilator |
|---|---|---|
| Age (months) | 30.5 (14.8) [26] | 22.4 (15.1) [22] |
| Gender (% male) | 16/26 (61.5%) | 16/25 (64.0%) |
| Adopted (%) | 10/26 (38.5%) | 7/25 (28.0%) |
| Reported wheeze with colds prior to study (%) | 12/26 (46.2%) | 7/25 (28.0%) |
| Reported wheeze apart from colds prior to study (%) | 4/26 (15.4%) | 5/25 (20.0%) |
| Reported number of visits to health center before 2 years of age | 4.3 (3.7) [25] | 2.9 (3.1) [25] |
| Reported number of admissions to regional hospital before 2 years of age | 0.4 (0.8) [26] | 0.2 (0.4) [25] |

Continuous variables are presented as mean (s.d.) [*n*]. There were no significant differences between the groups.

**Table 4** Comparison of baseline housing characteristics of subjects with active or placebo heat recovery ventilators

| Variable | Active heat recovery ventilator | Placebo heat recovery ventilator |
|---|---|---|
| Type of house (%) | | |
| Detached | 19/25 (76.0%) | 18/23 (78.3%) |
| Duplex | 6/25 (24%) | 5/23 (21.7%) |
| Type of heating (%) | | |
| Forced air | 18/25 (72.0%) | 20/23 (87.0%) |
| Radiator heat | 7/25 (28.0%) | 3/23 (13.0%) |
| Occupancy (persons/house) | 5.0 (2.1) [26] | 5.9 (2.5) [25] |
| Proportion children sharing bed with other(s) | 15/26 (57.2%) | 13/25 (52.0%) |
| Proportion living with smoker(s) (%) | 21/26 (80.8%) | 23/25 (92.0%) |
| No. smokers in the home | 2.1 (1.8) [26] | 2.5 (1.6) [25] |

Continuous variables are presented as mean (s.d.) [*n*].

**Table 5** Mean indoor air parameters (s.d.) in houses with active or placebo heat recovery ventilators (Mann–Whitney test)

| Characteristic | Houses with active heat recovery ventilators ($n = 19$) | Houses with placebo heat recovery ventilators ($n = 16$) | *P*-value |
|---|---|---|---|
| Mean $CO_2$ (ppm) | 915.2 (163.2) | 1358.7 (539.3) | 0.002 |
| Mean relative humidity (%) | 25.3 (2.8) | 30.3 (5.7) | 0.008 |
| Mean indoor temperature (°C) | 23.2 (1.6) | 24.1 (1.3) | 0.14 |

tuberculosis (1/68, 1.5%). Occupancy rates and rates of exposure to ETS were high (Table 4). No hospitalizations occurred during the study. The rate of community health center or regional hospitalization(s) for lower respiratory tract infection was significantly higher in the first 2 years of life than during the study (data available on request).

Indoor air quality data was available for 35 homes. The mean indoor $CO_2$ in homes with active HRVs was 33% lower ($P = 0.002$) than in homes with placebo ventilators (Table 5). Mean relative humidity was significantly reduced ($P = 0.008$). There were no significant differences in the mean temperature.

Over the course of the winter season, rates of reported wheezing rose in the placebo group but not in the active HRV group (Table 6). Repeated measures analysis of subjects confirmed that use of an active HRV, compared with placebo, was associated with a progressive fall in the odds ratio for reported wheeze of 12.3% per week (95%CI 1.9%–21.6%, $P = 0.022$) (Figure 5). By 5 months, the odds ratio of reported wheeze with HRV use was 0.13 (95%CI 0.025–0.83, $P = 0.030$. Rates of reported rhinitis (not associated with cold air exposure) were significantly lower in the HRV group than the placebo group in month 1 (odds ratio 0.20, 95%CI 0.058–0.69, $P = 0.011$) and in month 4 (odds ratio 0.24, 95%CI 0.054–0.90, $P = 0.035$) (Table 6). There was a non-significant reduction in the OR for reported cough (OR 0.56, 95%CI 0.27–1.18, $P = 0.13$). Reported attacks of shortness of breath were infrequent in both groups (data not presented). There were no significant differences between groups in the number of visits to the community health centers for any reason (0.6 vs. 0.5 visits/subject in the active and placebo groups, respectively, $P = 0.77$), respiratory illness, or otitis media (data not presented).

Reported concerns about the study devices occurred with similar frequencies in both groups (Table 7). The frequency that households dismantled or failed to use their units for most of the study period tended to be higher for placebo units (14/33, 42.4%) than active units (8/29, 27.6%), although the difference was not statistically significant ($P = 0.29$).

## Discussion

Previous research associated increased levels of occupancy and reduced ventilation rates with an increased risk of lower respiratory tract infection in Inuit

**Table 6** Frequency and odds ratios for rhinitis and wheezing for children in houses with active or placebo heat recovery ventilators

| | Week frequency (%) | 4 | 8 | 12 | 16 | 20 | 24 |
|---|---|---|---|---|---|---|---|
| Wheezing | | | | | | | |
| HRV | Wheezing | 3 (11.5) | 4 (16.0) | 1 (4.0) | 2 (9.1) | 2 (11.8) | 0 (0.0) |
| | No wheeze | 23 (88.5) | 21 (84.0) | 24 (96.0) | 20 (90.9) | 15 (88.2) | 12 (100) |
| | Odds of wheezing | **0.13** | **0.19** | **0.042** | **0.10** | **0.13** | **0.00** |
| Placebo | Wheezing | 3 (12.0) | 5 (20.8) | 3 (14.3) | 4 (22.2) | 6 (50.0) | 4 (50) |
| | No wheeze | 22 (88.0) | 19 (79.2) | 18 (85.7) | 14 (77.8) | 6 (50.0) | 4 (50) |
| | Odds of Wheezing | **0.14** | **0.27** | **0.17** | **0.29** | **1.00** | **1** |
| | Odds ratio of wheezing (HRV/placebo) [95%CI] | **0.96 [0.17, 5.43]** | **0.72 [0.16, 3.20]** | **0.25 [0.022, 2.89]** | **0.35 [0.058, 2.05]** | **0.13 [0.025, 0.83]** | **0.00 [0.0074, 0.36]*** |
| Rhinitis (apart from cold air) | | | | | | | |
| HRV | Rhinitis | 6 (23.1) | 14 (56.0) | 16 (64.0) | 10 (45.5) | 8 (47.1) | 6 (50.0) |
| | No Rhinitis | 20 (76.9) | 11 (44.0) | 9 (36.0) | 12 (54.5) | 9 (52.9) | 6 (50.0) |
| | Odds of Rhinitis | **0.30** | **1.27** | **1.78** | **0.83** | 0.89 | **1.00** |
| Placebo | Rhinitis | 15 (60.0) | 9 (37.5) | 15 (71.4) | 14 (77.8) | 9 (75.0) | 5 (62.5) |
| | No Rhinitis | 10 (40.0) | 15 (62.5) | 6 (28.6) | 4 (22.2) | 3 (25.0) | 3 (37.5) |
| | Odds of Rhinitis | **1.50** | **0.60** | **2.50** | **3.50** | **3.00** | **1.67** |
| | Odds ratio of Rhinitis (HRV/placebo) [95%CI] | **0.20 [0.058, 0.69]** | **2.12 [0.65, 6.54]** | **0.71 [0.18, 2.40]** | **0.24 [0.054, 0.90]** | **0.30 [0.051, 1.56]** | **0.60 [0.083, 3.86]** |

*The 95%CI is calculated using empirical logit as described in the Statistical analysis section.
Odds ratio are bold.

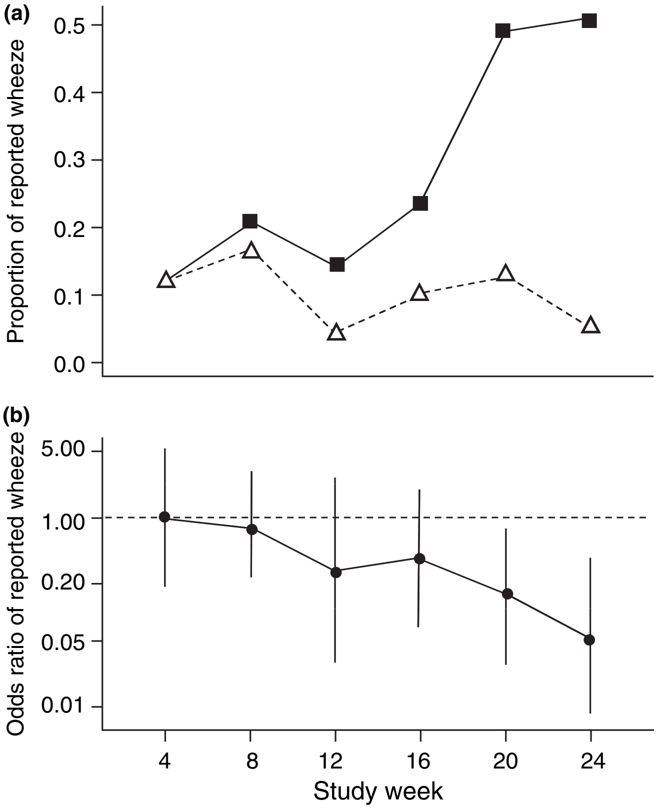

**Fig. 5** Wheezing during the study period in each groups. (a) Proportion of subjects over time reporting wheeze in the placebo and active heat recovery ventilator (HRV) groups (solid line and filled squares – placebo, dashed line and open triangles – active group). (b) Odds ratio between the two groups for reporting wheeze along with 95%CIs. Odds ratios less than 1 favor the active HRV group

**Table 7** Reported concerns about the heat recovery ventilators in the active and placebo groups

| Concern | Details | Active (*n* = 29) | Placebo (*n* = 33) |
|---|---|---|---|
| House colder | | 4 | 4 |
| House drier | | 2 | 5 |
| Unit too noisy | | 1 | 2 |
| Health concerns | Headache | 1 | |
| | Epistaxis | 1 | |
| | Increased cough and/or infections (child) | | 2 |
| | More dyspnea with colds (parent) | | 1 |
| Other building concerns | Unit brings in dust and/or fumes from outside or neighboring house | 1 | 2 |
| Total number of concerns | | 10 | 16 |

children (Kovesi et al., 2006, 2007). We observed that HRVs improved ventilation and reduced the risk of wheezing and rhinitis in this population. No hospitalizations occurred in either group, and subjects, on average, had few visits to the local community health center.

A recent systematic review concluded that there is good evidence that reduced ventilation is associated with an increased risk of respiratory infection with several infectious agents, including influenza virus. However, previous studies were generally not conducted in houses (Li et al., 2007). We are aware of only one previous published study that evaluated HRVs in houses (Warner et al., 2000), although two others have been published as abstracts (Rosenbaum et al., 2008; Wright et al., 2008). HRVs improved ventilation and reduced relative humidity in homes (Rosenbaum et al., 2008; Warner et al., 2000; Wright et al., 2008). Previous studies evaluated whether these devices, by reducing indoor humidity, would decrease dust-mite antigen concentrations (Warner et al., 2000) and therefore asthma and allergy symptoms in individuals with dust-mite allergies. However, since dust-mite antigen concentrations are virtually undetectable in Nunavut houses (Kovesi et al., 2006), this is not relevant to our population. HRVs, in combination with room air cleaners and vacuum cleaners, reduced airborne particulates, indoor $CO_2$, and indoor carbon monoxide in children with asthma (Rosenbaum et al., 2008).

Rates of respiratory disease (Banerji et al., 2001) and symptoms (Koch et al., 2002) are markedly elevated in Inuit children, and the high prevalence of ETS exposure likely contributes to this (Li et al., 1999; Nafstad et al., 1997; Rushton, 2004). Both findings may enhance detection of a treatment effect in this population. We previously observed that concentrations of airborne nicotine in the houses of young Inuit children were similar to those found in the houses of smokers in the continental United States. Airborne concentrations of nicotine were not significantly correlated to airflow ($r = 0.30$, $P = 0.245$) or air change rates ($r = 0.11$, $P = 0.686$); (Kovesi et al., 2006). It is possible that some of the beneficial effects of the HRVs on respiratory disease was because of reductions in concentrations of indoor air contaminants, but we did not measure the effect of the devices on contaminants such as ETS, and it is unclear to what extent concentrations of any contaminant(s) was reduced.

Our HRVs significantly reduced indoor $CO_2$. Houses with active units had mean indoor $CO_2$ concentrations within the Canadian recommended guidelines of less than 1000 ppm (Health Canada, 1989). Houses with placebo units had elevated $CO_2$ concentrations, consistent with data obtained previously in many communities in Qikiqtaaluk region (Kovesi et al., 2006, 2007). Modeling studies have suggested a reduction of indoor $CO_2$ concentrations below 1000 ppm may reduce the risk of transmission of common respiratory pathogens (Rudnick and Milton, 2003). In young children, rhinitis not associated with cold air exposure is primarily caused by viral upper respiratory tract infections, particularly in the wintertime (Koch et al., 2002). We found that HRVs decreased the risk of reported rhinitis. A conservative explanation of this is that the improved ventilation rate decreased the frequency of upper respiratory tract infections (Myatt et al., 2004). Wheezing is most commonly triggered by acute viral respiratory infections in young children. The significant reduction in wheezing we observed is most likely because of a reduction in viral upper respiratory infections (Martinez et al., 1995). Wheezing rates rose during the study in the placebo group, likely because of increased exposure to respiratory viruses during mid-winter, when rates of viral infection peak in the arctic (Singleton et al., 2006). Asthma and atopy, including allergy to house dust-mites, are not common in Inuit children (Gao et al., 2008; Hemmelgarn and Ernst, 1997) and these houses have negligible concentrations of dust-mite allergens (Hemmelgarn and Ernst, 1997; Kovesi et al., 2006), so a potential reduction in dust-mite levels cannot explain our results. In the case of influenza virus, aerosol, rather than droplet or direct contact spread, is more likely to lead to lower respiratory tract infection (Salgado et al., 2002). A large study of American office buildings found that indoor $CO_2$ concentrations were associated with reported wheezing in adults with asthma, possibly because of increased concentrations of a variety of indoor air contaminants (Erdmann and Apte, 2004). Improving home ventilation may therefore reduce the risk of wheezing by multiple mechanisms.

The term ‘wheezing’ may be misinterpreted in a community setting (Elphick et al., 2001). The term is problematic in Inuktitut, where there is no precise term for ‘wheezing’ (Kovesi, 2008), but we carefully ensured that our research assistants would translate the term as accurately as possible with the assistance of professional Inuit health translators. We used a standard respiratory questionnaire that has been carefully validated (Torén et al., 1993) and used in many cultures (Chatkin and Menezes, 2005; Langkulsen et al., 2006). It has been subsequently adapted for use in international surveys on childhood asthma (Pearce et al., 1993). We did not validate symptoms reported in the questionnaires against symptoms noted during health center encounters, and we did not assess the reproducibility of the families’ reports.

Our findings emphasize the importance of community education, and taking occupant perceptions and beliefs into consideration, when planning home air quality interventions (National Research Council and Institute of Medicine, 2005). This will be important both for future research projects, designing new housing, and retrofitting current homes. Perceptions of indoor air temperature appear to be very important in traditional Inuit culture, and likely influenced the acceptability of the HRVs. The communities were concerned that the devices would make the houses colder and/or raise electricity bills. This reduced recruitment, and led to several units being unplugged or dismantled (Kovesi, 2007). More intensive community education prior to the study might have helped avert this. We investigated the concerns of families near the onset of the study that the units were making houses colder. We found that the installers had not balanced the units according to the manufacturer’s specifications. In some cases, there may have been greater ingress of cold air during extremely cold weather because the warming capacity of the HRV to warm outside air was exceeded. The units were subsequently balanced and we instructed families that they could temporarily unplug units when outside conditions were extremely cold. Mean temperatures in both groups of houses remained higher than usually occurs in southern Canada (Kovesi et al., 2006). Both active and placebo units increased air circulation within houses which may have led to a perception that the houses were more drafty. Relative humidity is low in houses in Nunavut (Kovesi et al., 2006). While the modest reduction in relative humidity by the active devices might have affected occupant comfort, the active units tended to be unplugged less often than the placebos, suggesting that the ventilators instead in fact improved resident comfort. The cost of the HRV we used in the study is approximately $2420 (Canadian) in southern Canada (including installation) (Expair.ca, 2009), and the electrical operating cost is approximately 1000 kW h/year or $100 at $0.10/kW h (Venmar Ventilation Residential Product Group, 2003).

In addition to under-utilization of some of the devices, a number of other factors limited our analysis. Several children were removed from the study because they changed houses during the data collection period. Movement of children between families is common in Inuit culture: young Inuit children in Nunavik (arctic Quebec) were frequently (23.8%) given for adoption (Dallaire et al., 2004). Data collection occurred when the children were older than originally planned. While we previously found that reduced ventilation was associated with an increased risk of respiratory tract infection in children below 5 years of age (Kovesi et al., 2007), this risk appears to be largely confined to the first 2 years of life. Similar observations have been noted in Nunavik (Dallaire et al., 2004). This also affected our power calculations. While a sample size of 49 houses per group was planned to detect a clinically significant reduction in hospitalization rates with 80% power (Current Controlled Trials, 2007), as no hospitalizations occurred, the planned statistical analysis on hospitalization rates could not be performed. Although our sample size was limited, it is one of the largest trials of an indoor air quality intervention. For example, a systematic review of the effect of air filtration systems identified 10 trials, with a sample size ranging from 9 to 45 participants (McDonald et al., 2002).

In conclusion, improving ventilation significantly reduced the incidence of important respiratory symptoms in young Inuit children. Additional research is required to explore preferences in Inuit culture regarding air movement in dwellings, given occupant concerns about the active and placebo devices. This information may help improve the tolerability of mechanical ventilators by Inuit families living in the far North. Our study suggests that a multifaceted approach, including reducing overcrowding by providing more housing stock, improving indoor ventilation, decreasing ETS exposure (Koch et al., 2003), and enhancing immunization strategies (Singleton et al., 2003), will be necessary to reduce the burden of lower respiratory tract infection and chronic disease in Inuit children.

## Acknowledgements

This study was made possible with the support of the following organizations and individuals: Isaac Sobol, Chief Medical Officer of Health, Nunavut Department of Health and Social Services (Iqaluit, Nunavut), Peter Scott, President, Nunavut Housing Corporation (Iqaluit, Nunavut), John MacDougall (Qikiqtani Inuit Association, Iqaluit, Nunavut), Children's Hospital of Eastern Ontario Research Institute (Ottawa, Ontario), Nunavut Department of Education (Iqaluit, Nunavut), Ilinniariusarvik Igloolik Head Start Program (Igloolik, Nunavut). We thank our research assistants and coordinators: Carolyn MacDonald (Igloolik), Raygelee Mike (Pangnirtung), Shelly Elverum (Pond Inlet), Shari Gearhead (Clyde River). This study was supported by Health Canada, the Canada Mortgage and Housing Corporation and the Program of Energy Research and Development, Natural Resources Canada (Grant no. PERD–089), Ottawa, ON, Canada.

## Sources of support

Program of Energy Research and Development, Natural Resources Canada.

Nasivvik ACADRE Inuit Centre, Canadian Institutes of Health Research, Health Canada, Ottawa, Canada.

Canada Mortgage and Housing Corporation, Ottawa, Canada.

## Funding and commercial interests

Venmar Ventilation Inc. provided the HRVs at the cost of manufacture and provided technical expertise to our engineers on a *pro bono* basis. The project purchased the parts and units and paid all shipping costs using funding from the Program of Energy Research and Development (Natural Resources Canada) and Canada Mortgage and Housing Corporation. None of the investigators have financial relationships with the manufacturer, and Venmar Ventilation Inc. had no role in gathering or publishing the data obtained.

## References

Agresti, A. (1991) *Categorical Data Analysis*, 1st edn. New York, NY, John Wiley and Sons.

American Society of Heating Refrigerating and Air Conditioning Engineers Inc., (1997) *1997 ASHRAE Fundamentals Handbook*, Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (25.5).

Banerji, A., Bell, A., Mills, E.L., McDonald, J., Subbarao, K., Stark, G., Eynon, N. and Loo, V.G. (2001) Lower respiratory tract infections in Inuit infants on Baffin Island, *CMAJ*, **164**, 1847–1850.

Chatkin, M.N. and Menezes, A.M.B. (2005) Prevalence and risk factors for asthma in schoolchildren in southern Brazil, *J. Pediatr (Rio J)*, **81**, 411–416.

Current Controlled Trials, (2007) *ISRCTN71224182 – Randomized Trial of Heat Recovery Ventilators (HRVs) for the Prevention of Severe Lower Respiratory Tract Infection (LRTI) in Inuit Infants in Baffin Region*, Nunavut, Canada. Available at: http://www.controlled-trials.com/ISRCTN71224182/kovesi [accessed on 11 April 2009].

Dallaire, F., Dewailly, E., Muckle, G., Vezina, C., Jacobson, S.W., Jacobson, J.L. and Ayotte, P. (2004) Acute infections and environmental exposure to organochlorines in Inuit infants from Nunavik, *Environ. Health Perspect*., **112**, 1359–1365.

Elphick, H.E., Sherlock, P., Foxall, G., Simpson, E.J., Shiell, N.A., Primhak, R.A. and Everard, M.L. (2001) Survey of respiratory sounds in infants, *Arch. Dis. Child*., **84**, 35–39.

Environment Canada, (2008) National climate data and information archive. Available at: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [accessed on 27 January 2009].

Erdmann, C.A. and Apte, M.G. (2004) Mucous membrane and lower respiratory building related symptoms in relation to indoor carbon dioxide concentrations in the 100-building BASE dataset, *Indoor Air*, **14**(Suppl 8), 127–134.

Expair.ca. (2009) Venmar Constructo 1.5. Available at: http://www.expair.ca/en/products-details/hrv_heat_recovery_ventilation/venmar_constructo_1_5 [accessed on 11 April 2009].

Ferris, B.G. (1978) Epidemiology standardization project (American Thoracic Society), *Am. Rev. Respir. Dis*., **118**(6 part 2), 1–120.

Gao, Z., Rowe, B.H., Majaesic, C., O'Hara, C. and Senthilselvan, A. (2008) Prevalence of asthma and risk factors for asthma-like symptoms in Aboriginal and non-Aboriginal children in the northern territories of Canada, *Can. Respir. J*., **15**, 139–145.

Health Canada, (1989) *Exposure Guidelines for Residential Indoor Air Quality: A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health*, Ottawa, Canada, Health Canada Publications/Communications.

Hemmelgarn, B. and Ernst, P. (1997) Airway function among Inuit primary school children in far northern Quebec, *Am. J. Respir. Crit. Care Med*., **156**, 1870–1875.

Herbert, F.A., Wilkinson, D., Burchak, E. and Morgante, O. (1977) Adenovirus type 3 pneumonia causing lung damage in childhood, *Can. Med. Assoc. J*., **116**, 274–276.

Johansson, A., Ludvigsson, J. and Hermansson, G. (2008) Adverse health effects related to tobacco smoke exposure in a cohort of three-year olds, *Acta Paediatr*., **97**, 354–357.

Karron, R.A., Singleton, R.J., Bulkow, L., Parkinson, A., Kruse, D., DeSmet, I., Indorf, C., Petersen, K.M., Leombruno, D., Hurlburt, D., Santosham, M. and Harrison, L.H. (1999) Severe respiratory syncytial virus disease in Alaska native children, *J. Infect. Dis*., **180**, 41–49.

Koch, A., Sorensen, P., Homoe, P., Molbak, K., Pedersen, F.K., Mortensen, T., Elberling, H., Eriksen, A.M., Olsen, O.R. and Melbye, M. (2002) Population-based study of acute respiratory infections in children, Greenland, *Emerging Infect. Dis*., **8**, 586–593.

Koch, A., Molbak, K., Homoe, P., Sorensen, P., Hjuler, T., Olesen, M.E., Pejl, J., Pedersen, F.K., Olsen, O.R. and Melbye, M. (2003) Risk factors for acute respiratory tract infections in young Greenlandic children, *Am. J. Epidemiol*., **158**, 374–384.

Kovesi, T. (2007) Qallunaat, *CMAJ*, **177**, 1018.

Kovesi, T. (2008) Re: Gao Z, Rowe BH, Majaesic C, O'Hara C, Senthilselvan A. Prevalence of asthma and risk factors for asthma-like symptoms in Aboriginal and non-Aboriginal children in the northern territories of Canada, *Can. Respir. J*., **15**, 139–145. *Can. Respir. J.,* **15**, 240.

Kovesi, T., Creery, D., Gilbert, N.L., Dales, R., Fugler, D., Thompson, B., Randhawa, N. and Miller, J.D. (2006) Indoor air quality risk factors for severe lower respiratory tract infections in Inuit infants in Baffin Region, Nunavut: a pilot study, *Indoor Air*, **16**, 266–275.

Kovesi, T., Gilbert, N.L., Stocco, C., Fugler, D., Dales, R.E., Guay, M. and Miller, J.D. (2007) Indoor air quality and the risk of lower respiratory tract infections in young Canadian Inuit children, *CMAJ*, **177**, 155–160.

Langkulsen, U., Jinsart, W., Karita, K. and Yano, E. (2006) Respiratory symptoms and lung function in Bangkok school children, *Eur. J. Public Health*, **16**, 676–681.

Li, J.S., Peat, J.K., Xuan, W. and Berry, G. (1999) Meta-analysis on the association between environmental tobacco smoke (ETS) exposure and the prevalence of lower respiratory tract infection in early childhood, *Pediatr.Pulmonol*., **27**, 5–13.

Li, Y., Leung, G.M., Tang, J.W., Yang, X., Chao, C.Y., Lin, J.Z., Lu, J.W., Nielsen, P.V., Niu, J., Qian, H., Sleigh, A.C., Su, H.J., Sundell, J., Wong, T.W. and Yuen, P.L. (2007) Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review, *Indoor Air*, **17**, 2–18.

Martinez, F.D., Wright, A.L., Taussig, L.M., Holberg, C.J., Halonen, M. and Morgan, W.J. (1995) Asthma and wheezing in the first six years of life. The Group Health Medical Associates, *N. Engl. J. Med*., **332**, 133–138.

McDonald, E., Cook, D., Newman, T., Griffith, L., Cox, G. and Guyatt, G. (2002) Effect of air filtration systems on asthma: a systematic review of randomized trials, *Chest*, **122**, 1535–1542.

Myatt, T.A., Johnston, S.L., Zuo, Z., Wand, M., Kebadze, T., Rudnick, S. and Milton, D.K. (2004) Detection of airborne rhinovirus and its relation to outdoor air supply in office environments, *Am. J. Respir. Crit. Care Med*., **169**, 1187–1190.

Nafstad, P., Kongerud, J., Botten, G., Hagen, J.A. and Jaakkola, J.J. (1997) The role of passive smoking in the development of bronchial obstruction during the first 2 years of life, *Epidemiology*, **8**, 293–297.

National Research Council and Institute of Medicine, (2005) *Ethical Considerations for Research on Housing-Related Health Hazards Involving Children. Committee on Ethical Issues in Housing-Related Health Hazard Research Involving Children, Youth, and Families*. Washington DC, The National Academies Press.

Pearce, N., Weiland, S., Keil, U., Langridge, P., Anderson, H.R., Strachan, D., Bauman, A., Young, L., Gluyas, P., Ruffin, D., Crane, J. and Beasley, R. (1993) Self-reported prevalence of asthma symptoms in children in Australia, England, Germany and New Zealand: an international comparison using the ISAAC protocol, *Eur. Respir. J*., **6**, 1455–1461.

Rosenbaum, P.F., Abraham, J.L., Siwinski, G. and Fernandez, A. (2008) Improvement in air quality parameters in intervention study homes of asthmatic children [abstract], *Am. J. Respir. Crit. Care Med*., **177**, A187.

Rudnick, S.N. and Milton, D.K. (2003) Risk of indoor airborne infection transmission estimated from carbon dioxide concentration, *Indoor Air*, **13**, 237–245.

Rushton, L. (2004) Health impact of environmental tobacco smoke in the home, *Rev. Environ. Health*, **19**, 291–309.

Salgado, C.D., Farr, B.M., Hall, K.K. and Hayden, F.G. (2002) Influenza in the acute hospital setting, *Lancet Infect. Dis*., **2**, 145–155.

Singleton, R., Morris, A., Redding, G., Poll, J., Holck, P., Martinez, P., Kruse, D., Bulkow, L.R., Petersen, K.M. and Lewis, C. (2000) Bronchiectasis in Alaska Native children: causes and clinical courses, *Pediatr. Pulmonol*., **29**, 182–187.

Singleton, R., Dooley, L., Bruden, D., Raelson, S. and Butler, J.C. (2003) Impact of palivizumab prophylaxis on respiratory syncytial virus hospitalizations in high risk Alaska Native infants, *Pediatr. Infect. Dis. J*., **22**, 540–545.

Singleton, R.J., Bruden, D., Bulkow, L.R., Varney, G. and Butler, J.C. (2006) Decline in respiratory syncytial virus hospitalizations in a region with high hospitalization rates and prolonged season, *Pediatr. Infect. Dis. J.*, **25**, 1116–1122.

Torén, K., Brisman, J. and Järvholm, B. (1993) Asthma and asthma-like symptoms in adults assessed by questionnaires. A literature review, *Chest*, **104**, 600–608.

Venmar Ventilation Residential Product Group, Venmar Constructo 1.5 heat recovery ventilator product sheet. Product Sheet Number 90281. February 2003. Drummondville, QC, Canada. Available at: http://www.expair.ca/files/produits/42_en.pdf [accessed on 11 April 2009].

Warner, J.A., Frederick, J.M., Bryant, T.N., Weich, C., Raw, G.J., Hunter, C., Stephen, F.R., McIntyre, D.A. and Warner, J.O. (2000) Mechanical ventilation and high-efficiency vacuum cleaning: a combined strategy of mite and mite allergen reduction in the control of mite-sensitive asthma, *J. Allergy Clin. Immunol.*, **105**(1 part 1), 75–82.

Wright, G.R., Chaudhuri, R., Howleson, S., McSharry, C., McMahon, A.D., Thompson, J., Fraser, I., King, E.M., Chapman, M.D., McAlpine, L., Wood, S. and Thomson, N.C. (2008) Effect of improved ventilation in the homes of adults with house dust mite-sensitive asthma [abstract], *Am. J. Respir. Crit. Care Med.*, **177**, A615.

YES Environment Technologies Inc. (2003) YES-206LH Series, Indoor Air Quality Monitor – Logger, Operation Manual. REV C. 12-3-2003. Delta, BC, Canada.

Young, M., Kandola, K., Mitchell, R. and Learmon, A. (2007) Hospital admission rates for lower respiratory tract infections in infants in the Northwest Territories and the Kitikmeot region of Nunavut between 2000 and 2004. *Paediatr. Child Health*, **12**, 563–566.