

The IVAIRE project – a randomized controlled study of the impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in single family homes

Abstract A randomized controlled trial was carried out to measure the impact of an intervention on ventilation, indoor air contaminants, and asthma symptoms of children. Eighty-three asthmatic children living in low-ventilated homes were followed over 2 years. Several environmental parameters were measured during the summer, fall, and winter. The children were randomized after Year 1 (43 Intervention; 40 Control). The intervention included the installation of either a Heat Recovery Ventilator (HRV) or Energy Recovery Ventilator (ERV). During the fall and winter seasons, there was a significant increase in the mean ventilation rate in the homes of the intervention group. A statistically significant reduction in mean formaldehyde, airborne mold spores, toluene, styrene, limonene, and α -pinene concentrations was observed in the intervention group. There was no significant group difference in change in the number of days with symptoms per 14 days. However, there was a significant decrease in the proportion of children who experienced any wheezing (≥ 1 episode) and those with ≥ 4 episodes in the 12-month period in the intervention group. This study indicates that improved ventilation reduces air contaminants and may prevent wheezing. Due to lack of power, a bigger study is needed.

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Practical Implications

Positive findings from this study include the fact that, upon recruitment, most of the single family homes with asthmatic children were already equipped with a mechanical ventilation system and had relatively good indoor air quality. However, the 8-h indoor guideline for formaldehyde ($50 \mu\text{g}/\text{m}^3$) was frequently exceeded and the ventilation rates were low in most of the homes, even those with a ventilation system. Both ERVs and HRVs were equally effective at increasing air exchange rates above 0.30 ACH and at preventing formaldehyde concentrations from exceeding the $50 \mu\text{g}/\text{m}^3$ guideline during the fall and winter seasons. Furthermore, the ERVs were effective at preventing excessively low relative humidities in the homes. Based on observed difference of risk, intervention to increase ventilation in five sample homes and children would prevent 1 home to exceed the indoor air long-term formaldehyde guideline and prevent 1 asthmatic child experiencing at least one episode of wheezing over a year.

Nomenclature

ACH	air change per hour
ASHRAE	American Society for Heating, Refrigerating, and Air-Conditioning Engineers
CFU	colony-forming unit
CG	control group
CI	confidence interval
CO ₂	carbon dioxide
ELISA	enzyme-linked immunosorbent assay
ERV	energy recovery ventilator
FW	fall–winter seasons
HDM	house dust-mites
HRV	heat recovery ventilator
ICS	inhaled corticosteroids
IG	intervention group
ISAAC	international study of asthma and allergies in childhood
MEA	malt extract agar
NO ₂	nitrogen dioxide
PEFR	peak expiratory flow rate
PFT	perfluorocarbon tracer gas technique
PM _{2.5}	fine particles
RH	relative humidity
S	summer season
s.e.	standard error
SF ₆	sulfur hexafluoride tracer gas technique
SVOCs	semi-volatile organic compounds
VOCs	volatile organic compounds

Introduction

For energy conservation purposes acknowledged since the end of the 1970s, buildings are now designed to be airtight through the use of new building and insulation materials (Angell et al., 2004). Consequently, ventilation rates are generally lower in newly built or renovated residential buildings, especially those located in cold climate regions (Sundell, 2004). Most of the time, for adequate ventilation, newer buildings need to be equipped with a mechanical ventilation system to provide an acceptable indoor environment. Ventilation rates measured in Northern European countries are somewhat under 0.50 air changes per hour (ACH), which is the recommended ventilation guideline in Scandinavia, whereas in Canada and the United States, they are often under 0.35 ACH, which is the nominal ventilation rate recommended by ASHRAE, National Building Code of Canada, and others (Bornehag et al., 2005a,b; California Energy Commission, 2009; Clausen et al., 2012; Gilbert et al., 2006; Héroux et al., 2010; National Building Code of Canada, 2005; Wheeler et al., 2011). Current ventilation guidelines are not health based but instead have been designed to optimize occupant comfort through the control of

bioeffluents. The role of ventilation in residential buildings is to maintain good indoor air quality by removing contaminated air and introducing fresh, ambient air to dilute indoor contaminants (Spengler et al., 2001). Children in general and asthmatic children in particular, are highly vulnerable to indoor air pollution (Franklin, 2007; Hulin et al., 2012). Some studies suggest that increased ventilation may be associated with lower concentrations of air contaminants in the home and may be beneficial to reduce respiratory symptoms in asthmatic children in cold climate regions, especially when the home ventilation rate is increased to above 0.5 ACH (Sundell et al., 2011). A previous report published by the Institute of Medicine (2000) evaluated different mitigation strategies affecting indoor air pollutants implicated with asthma. It identified a critical need for more research studying the relationship between ventilation and asthma. Apart from an earlier study on the impact of ventilation and heating on the quality of life of 192 children with asthma in Wales, a moderate climate region, there are no randomized controlled field studies on the impact of mechanical ventilation on indoor air quality and asthma symptoms in children (Woodfine et al., 2011). The latter study showed a significant improvement in the quality of life of children with asthma, including parent-reported symptoms and treatment 4 and 12 months after the installation of an HRV in the homes. However, no environmental parameters were measured. The intervention in the homes also included improvements to the heating systems.

Considering the limited available evidence on environmental and health impacts of mechanical ventilation, the purpose of the IVAIRE¹ project was to evaluate the effectiveness of improved ventilation in single family homes of children with asthma on indoor air quality and their respiratory health. The specific objectives were to explore the impact of the intervention on ventilation rates, concentrations of indoor air contaminants, and the frequency of asthma-related respiratory symptoms. This general paper presents a comprehensive synthesis of the results of the study in regard to these three objectives.

Methodology

From October 2008 to June 2011, an unblinded randomized controlled study was conducted with 83 asthmatic children living in homes which, upon recruitment, had a ventilation rate <0.30 ACH. From July 2008 to July 2009, we enrolled children from 3 to

¹IVAIRE Project : *Impact de la Ventilation sur l’Air Intérieur et la Respiration des Enfants asthmatiques dans les habitations*—Impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in single family homes.

12 years of age who were referred to the study team by the physicians of the Asthma Clinic at the Centre mère-enfant of Centre Hospitalier Universitaire de Québec (CHUQ). All the children lived in the Greater Québec City Area. Inclusion and exclusion criteria are presented in Table 1. Each child along with the indoor environment of the participant's home was monitored for 2 years to collect health and environmental data. Year 1 addressed the pre-intervention phase to establish a baseline and in Year 2, the post-intervention phase, the monitoring was used to assess the effectiveness of the intervention. The intervention on ventilation was conducted in the summer or early fall of 2010 in the homes randomly selected to be in the intervention group.

The study was approved by the CHUQ, National Research Council Canada, and Health Canada ethics review boards. Written consent was obtained from each participant's parent, and children over age 7 gave their assent. A baseline environmental evaluation of each home was carried out by a team of technicians during the home visits, which took place in each home during the summer, fall, and winter between October 2008 and August 2010. The fall, winter, and early spring represent the heating seasons in cold climate regions. Building characteristics were assessed through a home inspection and environmental questionnaires. A variety of chemical parameters (CO_2 , VOCs, SVOCs, NO_2 , and formaldehyde), biologic parameters (settling and airborne mold spores, HDM allergens), and physical parameters (temperature, RH, $\text{PM}_{2.5}$, building envelope air tightness, and ventilation rate)

were measured during the summer, fall, and winter visits. During the summer, there was a reduced set of measured environmental parameters. The analysis of the environmental parameters presented in this manuscript will limit itself to those parameters found to be directly relevant to the measured health outcomes. Follow-on manuscripts will provide a more in-depth analysis of the different chemical, biologic, and physical parameters measured in this study.

Environmental measurements

The summary of the measurement protocol is presented in Table S1 and expanded in further detail below. The average ventilation rate in the child's bedroom and in the living room over a 6- to 8-day period were determined using the perfluorocarbon tracer gas (PFT) technique developed by the Tracer Technology Group at Brookhaven National Laboratory (Dietz and Cote, 1982). Analysis of triplicate capillary adsorption tube samplers (CATS), placed side-by-side, showed a standard deviation of <6% in the measured ventilation rate. The average difference between simultaneously measured ventilation rates in the child's bedroom and the living room was found to be 17%. In all cases, the homes were treated as a single zone. The ventilation rate was also measured over a 4- to 5-h period in the child's bedroom using sulfur hexafluoride (SF_6) tracer gas decay according to the ASTM test method E 741-00 (ASTM, 2006) using an Innova 1312 or 1412 photoacoustic field gas monitor. Building air tightness was measured using a Minneapolis Blower Door™ from

Table 1 List of inclusion and exclusion criteria related to health and buildings

Health	Building
A Inclusion criteria	
Children aged 3–12 years	Family living in the Greater Québec Area that is ≤ 45 min by car from downtown Québec City
Asthma diagnosed by a physician at the Mother Child Centre, based on the presence of one of the following signs or symptoms:	Single family home: bungalow, cottage, twin, duplex, triplex, quadruplex.
• Preschool (ages 3–5 years):	Family has lived in the home for the previous 12 months at least.
One severe episode of wheezing and dyspnea <i>and/or</i> wheezing and dyspnea which persists after 1 year of age <i>and/or</i> ≥ 3 episodes of wheezing <i>and/or</i> chronic coughing (especially nocturnal or associated with exercise) AND Relief of symptoms after use of asthma medication	Following measured ventilation rates:
• School-aged children $\geq$ age 6 years:	• 2 PFT or SF_6 results < 0.30 ACH.
12% or greater improvement in FEV_1 from the baseline after the administration of a bronchodilator (β_2 -agonist) <i>and/or</i> positive methacholine challenge test	• 1 PFT or SF_6 result < 0.25 ACH.
Asthma-related hospitalization <i>and/or</i> emergency visit <i>and/or</i> oral corticosteroid use in the previous 12 months	
B Exclusion criteria	
Very unstable asthma or family context not suitable for full participation based on a physician's advice	Significant environmental contamination of the building (water damage, mold, unsanitary conditions, etc.) requiring immediate remediation
Significant other lung comorbidity (e.g., cystic fibrosis).	Parents do not own the house
Child expected to be away from the home > 21 days during November through March	Major work planned in the dwelling during the study period that may modify isolation and ventilation
Child lives in another home on a regular basis (> 8 nights per month)	Commercial services offered to the public in the home (hair styling, kindergarten, others)
	Move planned within the next 3 years

The Energy Conservatory equipped with a DG-700 pressure and flow gauge, and the data were analyzed with the TECTITE Airtightness Test Analysis Software. The blower door test was conducted according to the ASTM E 779-03 test method (ASTM, 2003a).

Formaldehyde was measured in the child's bedroom over a 6- to-8 day period using duplicate Waters Sep-Pak XPOsure cartridges as a passive sampler. The cartridges were subsequently analyzed for formaldehyde using high-performance liquid chromatography (GC) according to the ASTM test method D 5197-03 (ASTM, 2003b). NO₂ was also measured in the child's bedroom. A detailed extraction and analysis protocol for the NO₂ impregnated filter pads can be obtained from Ogawa & Company (Ogawa, 2011). The concentration of NO₂ (0.32 ppb detection limit for a 7 day exposure) was determined on a Spectro UV-Vis Double Beam UVD-3500 spectrophotometer at a wavelength of 545 nm according to the ASTM test method D 1607-91 (ASTM, 2005). In the child's bedroom, RH and temperature were measured with an Onset HOBO U12-013 data logger and the CO₂ concentration was measured with a Vaisala GMW21 CO₂ sensor.

The VOCs were sampled on Perkin Elmer stainless steel ATD Passive samplers containing a Tenax TA 60/80 sorbent. Duplicate passive samplers and a blank were left in the child's bedroom for a period of 6–8 days (laboratory method for VOC analysis in Data S1).

The dust samples were taken on the floor of the child's bedroom and collected on a 70-mm diameter Whatman (GF/F) glass microfiber filter (Fischer Scientific, Ottawa, ON, Canada) using a RIDGID WD 4050 vacuum equipped with a purpose-built stainless steel sampling head (laboratory method for SVOC analysis in Data S2).

Allergen samples in dust were collected from the child's mattress and carpet, if present in the child's bedroom, using a Philips Topomatic T518 vacuum cleaner equipped with a Dustream™ collector from Indoor Biotechnologies. The dust samples were then sieved and analyzed by Aerotech Laboratories (USA) for house dust-mite (HDM) (*Der p 1*, *Der f 1*), cat (*Fel d 1*) and dog (*Can f 1*) allergens using an enzyme-linked immunosorbent assay (ELISA). Homes exceeding the sensitization levels (μg/g) in child's mattress dust for HDM *Der f 1*, HDM *Der p 1*, cat *Fel d 1*, and dog *Can f 1* allergens were identified (Pope et al., 1993). Airborne mold spores were measured using a Staplex model MAS-2 two-stage microbial air sampler for 5 min during each of the visits in the heating season in the child's bedroom, living room, and the basement. The spores were collected onto both dichloran 18% glycerol (DG-18)- and malt extract agar (MEA)-covered petri dishes. Settling mold spores were collected for 4–5 h in the child's bedroom onto both MEA- and

DG-18-covered petri dishes. Both the airborne and settling mold spore samples were incubated at 25 °C (77 °F) for 7 days then analyzed visually with a microscope to obtain a colony count.

Health measurements

The baseline health evaluation included an interview-administered questionnaire to parents on personal and medical history. It also included the International Study of Asthma and Allergies in Childhood ISAAC questionnaire² to parents on long-term prevalence of respiratory symptoms over 1 year (Asher et al., 1995). The French Canadian version of the core questionnaire for 6-/7-year-olds on asthma and rhinitis was used (questionnaire in Data S3). The Asthma Quiz was used to assess control of asthma over a 1-month period (questionnaire in Data S4) (Ducharme et al., 2004). A daily symptoms diary including asthma-related medication was completed by the parents for a short-term period of 2 weeks per month from November through March of each year (diary in Data S5) (Santanello, 2001). During those periods, the peak expiratory flow rate (PEFR) was measured twice daily at home among those 5 and older using the *Truzone* peak flow meter (Monaghan Medical Corporation, Trudell Medical International). Personal training of the parents was conducted by a nurse usually at home. The test has a relatively high degree of reproducibility; Tepper et al. reported, within-session and between-session coefficients of variation of 7% and 12%, respectively, among a population-based sample of 7-year-old children (Tepper et al., 2012). In the clinic, a skin test for allergies and respiratory function tests were obtained. Skin tests were carried out by an allergist using the prick test method described by Pepys (Pepys, 1975). According to current guidelines, the test was considered positive if the diameter of the wheal was 3 mm or more (Dreborg et al., 1989). The following eight antigens were tested: house dust (weight/volume 1:10), cat hair-epithelium and dog hair-dander (both 1:10), house dust-mites (30,000 PNU/ml), ragweed pollens (1:20), mixed trees (1:20), mixed grasses (1:20), and molds (*Alternaria* 1:10).

Randomization

As indicated in Figure 1, among the 111 participants who completed the baseline, at the end of the first year of monitoring, 83 children living in homes with low ventilation rates identified as having either one PFT/SF₆ result <0.25 ACH or two results <0.30 ACH were

²The International Study of Asthma and Allergies in Childhood: Phase 1 Manual <http://isaac.auckland.ac.nz/phases/phaseone/phaseonemanual.pdf> (Accessed on June 10, 2014).

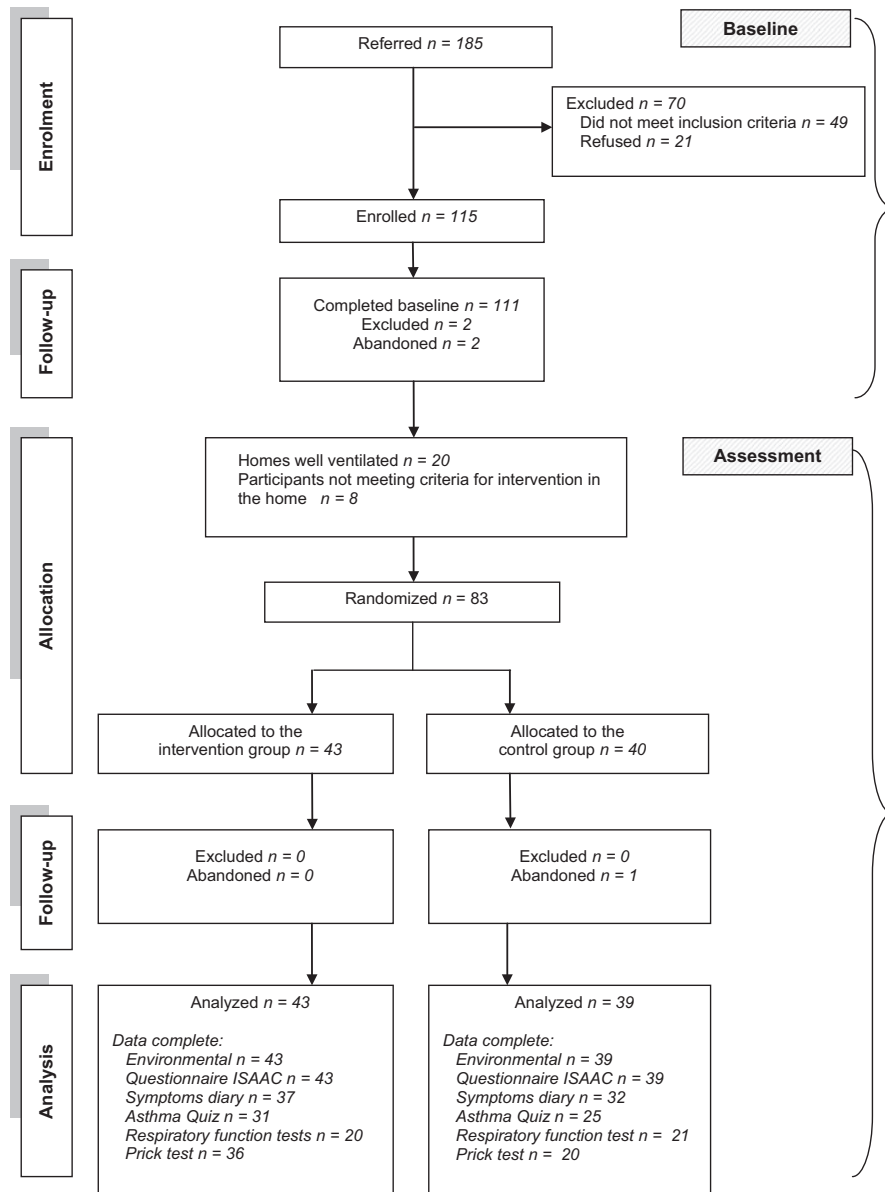


Fig. 1 Flow diagram – enrolment, randomization and retention of participants

enrolled by the study coordinator to participate in the second phase of the study, which included interventions on ventilation. Prior to being enrolled, those children had complied with selection criteria and had completed all baseline environmental visits and health questionnaires. During summer 2010, after giving their consent, they were randomly assigned to either the intervention or the control group following simple randomization procedures. Randomization was performed by the study statistician independently of the researchers and physicians and participants allocated using a personal identification code for each participant. For allocation, a computer-generated list of random numbers was used. The information about the allocation in the intervention and the control groups was withheld from all the participants except from

those of the intervention group in order for the interventions to be carried out by the firm in summer 2010. All the investigators and research staff members were masked to group assignment except for the study coordinator, who was responsible for the planning and the management of home visits, data gathering and interventions on ventilation.

Intervention on home ventilation

The interventions were planned and implemented between June and November 2010 by a Ventilation Task Force supervised by an engineer and senior researcher at Canada Mortgage and Housing Corporation (CMHC). The purpose of the interventions was to increase ventilation rates by 0.15 ACH in each

home of the intervention group by either optimizing the existing ventilation system or installing a new system. An individualized prescription, detailing the exact work required to increase the ventilation rates, was developed for each home in the intervention group based on the observations and measurements obtained during the pre-intervention phase (Year 1) of the study. For optimization purposes, technicians identified the technical characteristics of the ventilation system, corrections required to existing ducts, controls and equipment, and measured flow rates by flow hood method (Walker et al., 2001). The selection of a new HRV or an ERV was based on the volume of the house and building characteristics. ERVs, which can transfer moisture through their semi-permeable heat transfer core into the incoming outdoor air stream, were installed in the homes which had indoor RHs measurements lower than 35% RH and had other factors present, such as low heating-season indoor temperature, low number of occupants and the presence of mechanical ventilation, which could contribute to low indoor humidity levels during the heating-season. Overall, the intervention group had 19 ERVs and 24 HRVs installed or modified (summary of interventions on ventilation in Table S2). There were only three cases where the existing HRV was deemed acceptable and not replaced. A single contractor specializing in ventilation was hired to complete the work in all the homes. Venmar recovery ventilators were installed.

Prior to conducting the individual ventilation intervention, the precise prescription was modeled for several homes computationally and physically in NRC's purpose-built Indoor Air Research Laboratory (IARL). The computational fluid dynamics (CFD) calculations were performed using Fluent and were conducted to optimize the geometry and initial placement of any supply and return air vents in the child's bedroom that would be required during the installation of an HRV or ERV. The results of the computational models were then validated physically in a 1:1 scale model of the child's bedroom in the IARL. Measurements of SF₆ tracers gases, register flow rate, surface temperature, air temperature, and velocity profiles throughout the model bedroom were compared to those predicted with the CFD modeling. Good agreement was obtained between the computational and physical modeling. In most cases, the placement of a circular air supply register, supplying fresh air from the HRV and located at the center of the child's bedroom, provided better ventilation than placement near the door or along the wall.

A follow-up visit was carried out by the technician to check post-intervention flow rates against targeted objectives. The follow-up visit also included a personalized information session on the proper use and maintenance of the ventilation system by the occu-

pants. No intervention was carried out in the control group.

Follow-up health and home evaluations

From November 2010 to June 2011, the post-intervention monitoring was completed by the technicians during three home visits to measure ventilation rates, physical parameters, and indoor air contaminants. The daily symptoms diary and the Asthma Quiz were repeated by parents during the fall and winter seasons to ascertain symptoms and asthma control, as was the ISAAC questionnaire at the end of the second year to ascertain prevalence of wheezing.

Outcome measures

Based on the literature and on the preliminary data, the presumed causal chain of events between exposure and disease in the IVAIRE study included the three following sequential steps: (i) increase in the ventilation rate; (ii) reduction in asthma trigger by indoor air contaminants; and (iii) decrease in asthma symptoms. Three pre-specified primary outcomes were then identified: one health outcome and two intermediate environmental outcomes. The primary health outcome was the mean number of days with asthma symptoms, that is, at least one of the following symptoms: coughing, wheezing, chest tightness, disturbed sleep, and trouble breathing per 14-day period during fall and winter. The two primary environmental outcomes were ventilation rate as measured by the PFT technique and mean formaldehyde concentration ($\mu\text{g}/\text{m}^3$). Secondary health outcomes included the proportion of children with occurrence of at least one episode of wheezing during the previous 12 months measured by ISAAC questionnaire as well as the mean number of months with asthma control measured with the Asthma Quiz. Other health outcomes, concurrently with the daily symptoms diary, included the parent-reported mean number of days with use of relief medication as well as the mean peak expiratory flow rate (liters/minute) measured twice daily using the *Truzone* peakflow meter.

Secondary environmental outcomes included the mean RH, NO₂ concentration ($\mu\text{g}/\text{m}^3$), airborne mold spore count (CFU/m³), VOCs ($\mu\text{g}/\text{m}^3$), and selected SVOCs measured in house dust (ng/m²).

Statistical analysis

Concerning our primary health outcome, based on the studies of Lozano et al. (2003) and of Morgan et al. (2004), we estimated that to detect a reduction of 2.1 days (s.d. 4.69 days) with symptoms per 14-day period with a one-sided 5% significance test and a power of 80%, we would require a sample size of 60 children per group, given an anticipated drop out rate

of 15%. As for our secondary health outcome, we estimated that with that sample size, we could also detect with an 88% power a reduction of 20% of the proportion of children with at least one asthma-related symptom. Participants were required to have all ISAAC questionnaires and environmental home assessment visits completed for each year of the study in order to be included in the analysis. They must also have completed four 14-day daily symptom diary periods and four Asthma Quiz questionnaires during fall and winter seasons. One participant of the control group cannot be analyzed because he abandoned the study at the beginning of Year 2. That participant cannot be included in intention-to treat-analysis because the outcomes are missing (Moher et al., 2010). We calculated descriptive statistics of personal and home baseline characteristics of the participants according to group assignment. Non-normally distributed data (ventilation parameters, $PM_{2.5}$, chemical and biologic contaminants) were transformed into the corresponding log-normal distribution. Univariate and multivariate analysis was performed to study the relations between home characteristics and environmental parameters (ventilation, indoor air contaminants) as well as between personal characteristics and health parameters. Indeed for univariate analysis, Student's and χ^2 tests were used, respectively, to compare mean (or geometric mean) and proportion of environmental and health parameters according to potentially confounding variable. For multivariate analysis, linear models were used. The following potential confounding variables were identified: year of construction, the presence of an attached garage or woodstove, age, gender, parents' level of education, and eczema. Mixed linear models with repeated measures were used to evaluate the impact of the intervention on the change from Year 1 to Year 2 in environmental and health variables in the intervention group compared with the control group after adjustment for confounding variables. In the mixed models, confounding variables, environmental variables, as well as intervention and control groups, were specified as fixed effects. Subject was included as a random effect.

For log-transformed variables (geometric means), the Year 2 to Year 1 ratio was used to evaluate change from baseline in each group. To evaluate the group change, the Year 2 to Year 1 ratio of the intervention group was divided by the ratio of the control group. As for normally distributed variables (means), the difference (Year 2 – Year 1) was used to evaluate the change from baseline in each group. The difference between the intervention group and the control group was used to evaluate group change from baseline. Adjustment for year of construction and the presence of a woodstove was used for ventilation rate and relative humidity; adjustment for the presence of an attached garage was used for indoor air contaminant concentrations.

Adjustment for the child's age, gender, and eczema history, as well as the parents' level of education was used for asthma-related outcomes. Based on the method described by Morgan et al. (2004) in a randomized clinical trial on home-based environmental interventions among asthmatic children, in a *post hoc* analysis of environmental and health data, mixed linear models with repeated measures were used to assess whether a reduction in contaminants such as formaldehyde was associated with a decrease in symptoms in the intervention group. All statistical analyses were performed using SAS software (version 9.2; SAS Institute Inc., Cary, NC, USA).

Results

Study population

A total of 185 children were screened for possible enrollment in this study between October 2008 and June 2010 (Figure 1). Forty-nine (49) were ineligible and 21 refused to participate. One hundred and fifteen (115) children were enrolled in the pre-randomization phase of the study. Based on the results of the baseline environmental evaluation, a total of 83 children with a mean age of 6 years and living in homes with low ventilation rates were randomized and followed over the 1-year post-intervention phase. One participant abandoned at the beginning of Year 2 in the control group and was not included in the analysis.

Baseline health and environmental characteristics

The intervention and control groups had similar sociodemographic, health, and home characteristics (Table 2). The intervention children were somewhat younger. The population was made up mostly of boys, Caucasians and middle class families. About half were sensitized to at least one allergen, with 20% and 3% of the children sensitized to house dust-mites and molds, respectively. At baseline, the enrolled children were moderately to highly symptomatic with symptoms experienced mean 5.6 of 14 days; 75% and 40% of the children had a history of at least one asthma-related emergency visit and hospitalization for asthma during the previous year, respectively.

The baseline housing and indoor air quality characteristics of the homes of the intervention and control groups were similar. Sixty per cent (60%) of the homes had been built after 1980, and 75% were equipped with electric heating systems. The homes of the intervention group were somewhat newer and were more likely to have an attached garage (37% vs. 5%). There was a pet in 22% of the homes. Smoking took place in 3% of the homes. At baseline, 67% of the homes already had a mechanical ventilation system. During fall and

Table 2 Baseline characteristics of the children, homes, and environmental exposures during the fall–winter seasons.

Characteristics	Intervention group (<i>n</i> = 43) <i>n</i> (%)	Control group (<i>n</i> = 40) <i>n</i> (%)
Children		
Demographic		
Male gender	28 (65)	27 (68)
Mean age (<i>n</i> years ± s.e.)	5.5 ± 2.0	6.5 ± 2.9
Parents' level of education (college or university)	18 (44)	22 (56)
Upper-middle/upper family income	38 (90)	32 (84)
Children with family history of atopy		
1 parent	14 (33)	17 (44)
2 parents	16 (37)	13 (33)
Eczema or atopic dermatitis	9 (21)	18 (45)
Children with positive skin prick test		
At least one of eight common allergens ^a	16 (44.4)	15 (51.7)
Days with asthma-related symptoms (<i>n</i> per 14 days ± s.e.)	5.7 ± 0.5	5.6 ± 0.6
Months with asthma control based on Asthma Quiz (<i>n</i> per 4 months ± s.e.)	2.8 ± 0.2	2.8 ± 0.2
Medication		
Inhaled corticosteroids	25 (62.5)	26 (65.0)
Inhaled beta-agonists	35 (82.5)	30 (75.0)
Children with wheezing episodes during the past 12 months	31 (72.1)	31.0 (77.5)
Children with asthma-related healthcare use during the past 12 months		
Emergency visits	32 (74.4)	30 (75.0)
Hospitalizations	21 (48.8)	15 (37.5)
Homes		
Building		
Mean age (<i>n</i> years ± s.e.)	21.2 ± 3.1	24.6 ± 2.8
Attached garage	16 (37.2)	2 (5.0)
Woodstove	16 (37.2)	20 (50.0)
Heating system (electric)	36 (83.7)	27 (67.5)
Airtightness (< 3 ACH ₅₀)	17 (39.5)	10 (25.0)
Lifestyle		
Cat or dog	9 (20.9)	9 (22.5)
Smoking indoors	1 (2.3)	2 (5.0)
Dust-mites control measures	18 (41.9)	20 (50.0)
Ventilation equipment		
Mechanical ventilation system (HRV or air exchanger)	32 (74.4)	24 (60.0)
Heat recovery ventilator (HRV)	13 (30.2)	14 (35.0)
Air exchanger (with no heat recovery core)	19 (44.2)	10 (25.0)
Environmental exposures		
Ventilation		
PFT – EH ^b (ACH)		
Mean (95% C.I.)	0.17 (0.15–0.19)	0.18 (0.16–0.21)
Interquartile range	0.13–0.23	0.16–0.24
CO ₂ – EH (ppm)		
Mean (95% C.I.)	896 (809–991)	915 (826–1014)
Interquartile range	710–1145	746–1137
Physical		
PM _{2.5} (μg/m ³)		
Mean (95% C.I.)	1.75 (1.43–2.14)	1.61 (1.30–1.99)
Interquartile range	1.34–2.61	1.03–2.24
Relative humidity-LR ^c (%)		
Mean (95% C.I.)	39.1 (37.0–41.3)	41.6 (39.2–43.9)
Interquartile range	34.8–44.8	35.8–47.3
Temperature – LR		
Mean (95% C.I.)	21.1 (20.6–21.7)	20.8 (20.1–21.4)
Interquartile range	19.7–22.4	19.6–22.1

Table 2 Continued

Characteristics	Intervention group (<i>n</i> = 43) <i>n</i> (%)	Control group (<i>n</i> = 40) <i>n</i> (%)
Chemical		
Formaldehyde (μg/m ³)		
Mean (95% C.I.)	37.4 (32.3–43.3)	36.5 (31.1–42.7)
Interquartile range	26.5–53.3	27.2–50.7
Homes with formaldehyde ≥ 50 μg/m ³	13 (30.2)	10 (25.0)
Toluene (μg/m ³)		
Mean (95% C.I.)	25.9 (17.5–38.3)	14.1 (10.8–18.5)
Interquartile range	10.3–51.1	9.5–23.5
Nitrogen dioxide (NO ₂) (μg/m ³)		
Mean (95% C.I.)	3.40 (3.05–3.80)	3.3 (2.8–3.8)
Interquartile range	2.64–4.44	2.11–4.49
Biological		
Mold spores (CFU/m ³)		
Mean (95% C.I.)	101.3 (70.6–145.3)	88.7 (65.9–119.4)
Interquartile range	46.0–196.0	56.0–153.5
Dust-mites <i>Der f 1</i> (μg/g)		
Mean (95% C.I.)	0.06 (0.03–0.11)	0.15 (0.06–0.34)
Interquartile range	0.02–0.85	0.02–1.61
Dust-mites <i>Der p 1</i> (μg/g)		
Mean (95% C.I.)	0.02 (0.01–0.02)	0.02 (0.01–0.03)
Interquartile range	0.02–0.02	0.02–0.02

^aHouse dust, cat hair-epithelium, dog hair-dander, house dust-mites, ragweed pollens, mixed trees, mixed grasses, and molds.

^bEH, entire home.

^cLR, living room.

winter, the mean ventilation rate was 0.18 ACH in the homes, well below the nominal National Building Code of Canada (2005) recommended guideline of 0.30 ACH. The mean relative humidity was 40% in the living room during fall and winter seasons. The mean formaldehyde concentration during the fall and winter season was 37 μg/m³ and more than 25% of the homes had concentrations above the 8-h indoor air guideline of 50 μg/m³ (Health Canada, 2006). At baseline, the mean mattress *Der f 1* and *Der p 1* allergen concentrations were similar. The mean airborne mold spore concentration was 95 CFU/m³. Statistical tests have shown significant baseline group differences (*P* < 0.05) for following characteristics: history of eczema and food allergy, PEFR mean maximum and morning values, and construction year.

Effects of the intervention on ventilation rate and IAQ

As expected, during the fall and winter seasons, there was a significant group difference in the change of the geometric mean ventilation rate between Year 1 and Year 2, which was 1.77 times larger in intervention group than control group (*P* < 0.0001) (Table 3). The risk of having a home with ventilation rate <0.30 ACH was reduced by 62.3% (95% C.I.: 44.3–80.3) between Year 1 and Year 2 in the intervention group compared with the control group.

Table 3 Effects of ventilation interventions on ventilation and indoor air parameters in fall-winter (FW) and summer (S) periods

Outcomes	Intervention group (IG) (n = 43)		Change ^a (95% CI) at year 2	Control group (CG) (n = 39)		Change ^a (95% CI) at year 2	Comparison IG vs. CG	
	Year 1 (mean)	Year 2 (mean)		Year 1 (mean)	Year 2 (mean)		Δ change ^a (95% CI) at year 2	P value
Ventilation rates ^b								
PFT-FW-EH ^c (ACH)	0.17 (0.15–0.19)	0.34 (0.30–0.38)	2.00 (1.83; 2.18)	0.18 (0.16–0.21)	0.21 (0.18–0.23)	1.12 (1.02; 1.23)	1.77 (1.56; 2.02)	
Homes < 0.30 ACH (%)	95.4 (±5.7)	27.9 (±5.7)	–67.4 (–79.8; –55.0)	89.8 (±5.6)	84.7 (±5.6)	–5.1 (–18.1; 7.9)	–62.3 (–80.3; –44.3)	
PFT-FW-CBR ^c (ACH)	0.17 (0.15–0.19)	0.36 (0.32–0.41)	2.10 (1.91; 2.31)	0.19 (0.17–0.21)	0.21 (0.19–0.24)	1.12 (1.02; 1.24)	1.87 (1.62; 2.15)	
PFT-S-EH (ACH)	0.32 (0.23–0.45)	0.64 (0.46–0.90)	2.01 (1.42; 2.85)	0.42 (0.30–0.58)	0.48 (0.34–0.68)	1.15 (0.78; 1.67)	1.75 (1.05; 2.93)	
SF ₆ (ACH)	0.27 (0.25–0.30)	0.43 (0.39–0.47)	1.58 (1.43; 1.75)	0.25 (0.23–0.27)	0.30 (0.27–0.33)	1.20 (1.08; 1.34)	1.32 (1.13; 1.53)	
CO ₂ concentration ^b								
CO ₂ –FW-EH (ppm)	907 (829–993)	768 (701–840)	0.85 (0.78; 0.91)	924 (847–1009)	1058 (969–1155)	1.14 (1.06; 1.24)	0.74 (0.66; 0.83)	
CO ₂ –FW-CBR (ppm)	970 (883–1064)	792 (722–869)	0.82 (0.75; 0.89)	932 (851–1020)	1087 (994–1190)	1.17 (1.07; 1.27)	0.70 (0.62; 0.79)	
CO ₂ –S (ppm)	840 (761–927)	742 (672–818)	0.88 ^d (0.81; 0.97)	904 (821–994)	1023 (929–1126)	1.13 (1.03; 1.25)	0.78 (0.68; 0.89)	
Physical factors ^d								
Relative humidity-CBR (%)	44.4 (±1.2)	40.5 (±1.2)	–3.9 (–6.2; –1.6)	45.7 (±1.2)	48.3 (±1.2)	2.6 (0.2; 5.0)	–6.5 (–9.9; –3.2)	
Relative humidity-LR ^c (%)	39.2 (±1.1)	34.8 (±1.1)	–4.4 (–6.5; –2.3)	41.8 (±1.1)	43.4 (±1.1)	1.6 (–0.6; 3.8)	–6.0 (–9.1; –2.9)	
Temperature CBR	18.0 (±0.3)	16.8 (±0.3)	–1.1 (–1.6; –0.7)	17.2 (±0.3)	17.3 (±0.3)	0.1 (–0.4; 0.6)	–1.3 (–1.9; –0.6)	
Temperature LR	21.0 (±0.3)	21.2 (±0.3)	0.2 (–0.3; 0.6)	20.7 (±0.3)	21.0 (±0.3)	0.3 (–0.2; 0.7)	–0.1 (–0.7; 0.6)	
Chemical contaminants ^e								
Formaldehyde-FW								
Mean (μg/m ³)	37.2 (32.3–42.9)	24.1 (20.9–27.7)	0.65 (0.57; 0.73)	36.5 (31.2–42.6)	35.4 (30.3–41.4)	0.97 (0.86; 1.10)	0.67 (0.56; 0.79)	
Homes ≥ 50 μg/m ³ (%)	30.1 (±5.9)	0 (±5.9)	–30.2 (–42.9; –17.5)	25.5 (±6.5)	22.9 (±6.5)	–2.6 (–15.9; 10.8)	–27.7 (–46.1; –9.2)	
Formaldehyde-S								
Mean (μg/m ³)	56.5 (49.1–65.1)	47.1 (40.9–54.3)	0.83 (0.73; 0.96)	58.4 (50.0–68.2)	55.0 (46.9–64.5)	0.94 (0.81; 1.09)	0.89 (0.72; 1.08)	
Homes ≥ 50 μg/m ³ (%)	71.6 (±7.4)	41.3 (±7.4)	–30.2 (–45.9; –14.5)	75.6 (±8.1)	62.7 (±8.1)	–12.8 (–29.3; 3.7)	–17.4 (–40.2; 5.4)	
Comparison IG vs. CG								
Adjusted Δ change (95% CI) at year 2								
P value								
Outcomes								
Year 1 (mean)								
Year 2 (mean)								
Change ^a (95% CI) at year 2								
Control group (CG)								
(n = 39)								
Year 1								
Year 2								
Change ^a (95% CI) at year 2								
P value								
Chemical contaminants ^e								
Toluene (μg/m ³)								
28.7 (20.7–39.7)	7.8 (5.7–10.8)	0.27 (0.21; 0.36)	16.9 (11.8–24.1)	11.5 (8.0–16.4)	0.68 (0.51; 0.92)	0.40 (0.27; 0.60)	<0.0001	
3.40 (2.95–3.93)	4.99 (4.33–5.76)	1.47 (1.30; 1.65)	3.25 (2.78–3.81)	3.63 (3.11–4.25)	1.12 (0.99; 1.26)	1.31 (1.11; 1.56)	0.002	
5.2 (3.1–8.6)	2.6 (1.5–4.3)	0.50 (0.31; 0.79)	3.1 (1.8–5.4)	2.1 (1.2–3.7)	0.67 (0.41; 1.09)	0.74 (0.38; 1.44)	0.36	
0.49 (0.25–0.96)	0.03 (0.02–0.07)	0.07 (0.04; 0.14)	0.40 (0.19–0.84)	0.16 (0.08–0.33)	0.40 (0.19; 0.83)	0.18 (0.06; 0.49)	0.001	
44.3 (35.1–55.8)	14.7 (11.7–18.5)	0.33 (0.26; 0.42)	35.5 (27.6–45.8)	28.1 (21.8–36.2)	0.79 (0.62; 1.00)	0.42 (0.30; 0.58)	<0.0001	
15.5 (11.8–20.3) ^d	4.9 (3.7–6.4)	0.32 (0.25; 0.41)	10.0 (7.4–13.6)	8.0 (5.9–10.8)	0.80 (0.61; 1.03)	0.40 (0.28; 0.57)	<0.0001	
1415.2 (1183.2–1692.6)	2019.1 (1688.3–2414.9)	1.43 (1.15; 1.77)	1698.0 (1394.5–2067.5)	1723.5 (1418.0–2094.6)	1.01 (0.81; 1.27)	1.41 (1.03; 1.92)	0.03	
Biological contaminants ^f								
Air-borne mould spores (CFU/m ³)								
101.3 (72.8–140.8)	57.3 (41.2–79.7)	0.57 (0.40; 0.80)	89.8 (63.5–126.9)	91.0 (64.4–128.6)	1.01 (0.70; 1.47)	0.56 (0.34; 0.93)	0.03	
Allergens on child's mattress ^f								
HDM Der f 1 (μg/g)								
0.05 (0.03–0.12)	0.06 (0.03–0.13)	1.11 (0.57; 2.14)	0.16 (0.07–0.35)	0.21 (0.09–0.47)	1.35 (0.69; 2.67)	0.82 (0.32; 2.11)	0.67	
Homes Der f 1 > 2 μg/g (%) ^g	18.8 (±6.8)	18.8 (±6.8)	0 (–14.3; 14.3)	30.8 (±7.0)	38.5 (±7.0)	7.7 (–7.0; 22.4)	–7.7 (–28.2; 12.8)	
HDM Der p 1 (μg/g)	0.02 (0.01–0.02)	0.01 (0.01–0.02)	0.90 (0.71; 1.13)	0.02 (0.01–0.02)	0.02 (0.02–0.03)	1.14 (0.90; 1.46)	0.78 (0.56; 1.10)	0.16

Table 3 Continued

Outcomes	Intervention group (IG) (n = 43)		Control group (CG) (n = 39)		Comparison IG vs. CG	
	Year 1 (mean)	Year 2 (mean)	Change ^a (95% CI) at year 2	Year 1	Year 2	Adjusted Δ change (95% CI) at year 2
Cat <i>Fel d 1</i> ($\mu\text{g/g}$)	0.07 (0.04–0.13)	0.06 (0.03–0.12)	0.91 (0.51; 1.62)	0.07 (0.03–0.13)	0.06 (0.03–0.11)	1.06 (0.46; 2.46)
Homes <i>Fel d 1</i> > 1 $\mu\text{g/g}$ (%) ^b	16.5 (± 5.7)	16.3 (± 5.6)	–0.2 (–12.3; 11.9)	12.8 (± 5.9)	17.1 (6.0)	–4.5 (–22.1; 13.2)
Dog <i>Can f 1</i> ($\mu\text{g/g}$)	0.03 (0.02–0.05)	0.04 (0.02–0.06)	1.31 (0.73; 2.33)	0.03 (0.02–0.05)	0.03 (0.02–0.06)	1.26 (0.54; 2.90)
Homes <i>Can f 1</i> > 2 $\mu\text{g/g}$ (%) ^c	7.0 (± 4.2)	11.6 (± 4.2)	4.6 (–4.4; 13.6)	7.7 (± 4.4)	5.1 (± 4.4)	7.2 (–5.9; 20.2)

^aRatio of exposure (Year 2/Year 1) for log-transformed environmental variables; differences of proportions (%) (Year 2 – Year 1) for normally distributed variables.

^bGeometric means (95% C.I. limits) adjusted for the year of construction and the presence of a woodstove.

^cEH (entire home), CBR (child's bedroom), LR (living room).

^dArithmetic means adjusted for the year of construction and the presence of a woodstove.

^eGeometric means (95% C.I. limits) adjusted for the presence of an attached garage.

^fGeometric means (95% C.I. limits).

^gHomes with allergen level presenting higher risk of development of sensitization in the child.

The intervention on ventilation was associated with a 33% reduction between Year 1 and Year 2 in the geometric mean of formaldehyde concentration during the fall and winter seasons in the intervention group compared with the control group ($P < 0.0001$). The risk of exceeding 50 $\mu\text{g}/\text{m}^3$ formaldehyde concentration in the home of intervention group compared with the control group during fall and winter was reduced between Year 1 and Year 2 by 27.7%.

Over the 3-year time frame study (2008–2011), based on the data collected by Environment Canada at the Quebec City Airport meteorological station, the average outdoor temperatures of each year were -4.15°C , -2.20°C , and -3.20°C during fall (Nov–Dec); and -9.83°C , -4.20°C , and -8.13°C during winter (Jan., Feb. March), respectively. During the summer seasons, average outdoor temperatures were 17.6, 19.2 and 18.6 $^\circ\text{C}$, respectively. During the fall, winter, and summer seasons over the study period, average outdoor relative humidity levels were, respectively, 71.8%, 64.3%, and 58.0%. Overall, relative humidity was significantly reduced between Year 1 and Year 2 in the homes of the intervention group relative to the control group. We observed no significant impact of intervention on indoor temperature as measured in the living room. A small reduction was observed in the child's bedroom probably related to the addition of a new supply vent. Toluene, styrene, limonene, and α -pinene concentrations were significantly reduced from baseline in the intervention group compared with the control group as well as airborne mold spore concentrations. Compared with the control group, the intervention on ventilation had no significant effect in the change between Year 1 and Year 2 on the concentrations of allergens in both the mattress and area rugs in the child's bedroom. There was a 31% (1.31; 95% C.I.: 1.11–1.56) increase between Year 1 and Year 2 in the nitrogen dioxide concentration in the intervention group compared with the control group.

Effects of the intervention on asthma symptoms

For the primary outcome, there was no statistically significant group difference in the number of days with symptoms per 14 days (-0.6 per 14 days) between Year 1 and Year 2 (Table 4). As for the secondary outcome, there was a statistically significant group difference in the change between Year 1 and Year 2 in the proportion of children who experienced any wheezing (≥ 1 episode) (-22.1% (95% C.I.: -41.8 ; -2.3)) and those with ≥ 4 episodes (-20% (95% C.I.: -38.8 ; -1.1)) over a 12-month period.

There was, however, no group difference in the change from baseline in prevalence of rhinitis, emergency visits and hospitalizations, use of relief medication, asthma control, and PEFR.

Table 4 Effects of ventilation intervention on asthma symptoms, medication use, asthma control, and PEFR

Outcomes ^a	Intervention group (IG)			Control group (CG)			Comparison IG vs. CG Δ change ^b (95% CI) at year 2
	Year 1 (mean ± s.e.)	Year 2 (mean ± s.e.)	Change ^b (95% CI) at year 2	Year 1 (mean ± s.e.)	Year 2 (mean ± s.e.)	Change ^b (95% CI) at year 2	
Days with symptoms over 14 days (<i>n</i>)	(<i>n</i> = 37)			(<i>n</i> = 32)			
At least one symptom	5.9 ± 0.8	4.4 ± 0.8	−1.5 (−2.4; −0.5)	5.0 ± 0.9	4.1 ± 0.9	−0.9 (−1.9; 0.1)	−0.6 (−2.0; 0.9)
Coughing	5.3 ± 0.8	4.6 ± 0.8	−0.7 (−2.0; 0.5)	4.9 ± 0.9	3.5 ± 0.9	−1.4 (−2.7; 0.02)	0.6 (−1.3; 2.5)
Breathlessness	2.2 ± 0.5	2.0 ± 0.5	−0.2 (−1.3; 0.9)	1.0 ± 0.6	1.1 ± 0.6	0.1 (−1.0; 1.3)	−0.3 (−1.9; 1.3)
Disturbed sleep	1.7 ± 0.4	1.9 ± 0.4	0.2 (−0.6; 1.0)	1.2 ± 0.5	1.0 ± 0.5	−0.2 (−1.0; 0.7)	0.4 (−0.8; 1.5)
Wheezing	1.0 ± 0.4	0.9 ± 0.4	−0.0 (−0.8; 0.7)	0.7 ± 0.5	0.7 ± 0.5	0.0 (−0.8; 0.8)	0.0 (−1.1; 1.0)
Children with symptoms over a year (%) (<i>n</i> = 43)				(<i>n</i> = 39)			
Wheezing	77.4 ± 10.4	42.5 ± 10.4	−34.9 (−48.5; −21.3)	83.6 ± 10.4	70.8 ± 10.4	−12.8 (−27.1; 0.0)	−22.1 (−41.8; −2.3)
≥ 4 wheezing episodes	35.2 ± 8.9	5.0 ± 8.9	−30.2 (−43.2; −17.2)	33.8 ± 9.4	23.5 ± 9.4	−10.3 (−23.9; 3.4)	−20.0 (−38.8; −1.1)
Night coughing	62.1 ± 10.6	38.8 ± 10.6	−23.3 (−42.0; −4.5)	56.2 ± 11.2	48.6 ± 11.2	−7.7 (−27.3; 12.0)	−15.6 (−42.7; 11.6)
Rhinitis	74.2 ± 9.5	78.8 ± 9.5	4.7 (−11.2; 20.5)	79.4 ± 10.0	84.6 ± 10.0	5.5 (−11.5; 21.8)	−0.5 (−23.4; 22.5)
Children with emergency care over a year (%) (<i>n</i> = 43)				(<i>n</i> = 39)			
Emergency visit	73.6 ± 8.9	24.8 ± 8.9	−48.8 (−68.2; −29.5)	76.0 ± 9.4	24.7 ± 9.4	−51.3 (−71.6; −31.0)	2.4 (−25.6; 30.5)
Hospitalization	52.8 ± 7.7	8.6 ± 7.7	−44.2 (−60.0; −28.4)	43.9 ± 8.2	8.0 ± 8.2	−35.9 (−52.4; −19.4)	−8.3 (−31.1; 14.6)
Asthma relief medication use over 14 days (<i>n</i> = 37)				(<i>n</i> = 32)			
Days with relief medication (<i>n</i>)	3.3 ± 0.8	2.2 ± 0.8	−1.1 (−2.1; −0.1)	1.8 ± 0.9	1.8 ± 0.9	0.0 (−1.1; 1.1)	−1.1 (−2.6; 0.4)
Children with ≥ 8 doses (%)	32.6 ± 6.9	13.6 ± 6.9	−18.9 (−33.7; −4.1)	12.6 ± 7.6	12.6 ± 7.6	0.0 (−15.9; 15.9)	−18.9 (−40.7; 2.9)
Asthma control over 4 months (<i>n</i> = 31)				(<i>n</i> = 25)			
Months with control (<i>n</i>)	2.4 ± 0.3	2.6 ± 0.3	0.3 (−0.1; 0.6)	2.4 ± 0.4	2.7 ± 0.4	0.3 (−0.1; 0.7)	−0.01 (−0.6; 0.5)
Peak expiratory flow rate (PEFR) over all 14 day periods (<i>n</i> = 20)				(<i>n</i> = 21)			
Maximum value (L/min)	187.4 ± 32.9	232.1 ± 32.9	44.7 (17.9; 71.4)	214.1 ± 35.5	246.5 ± 35.5	32.5 (6.4; 58.6)	12.2 (−25.2; 49.6)
Morning value (L/min)	158.2 ± 24.9	192.5 ± 24.9	34.3 (16.0; 52.6)	184.5 ± 26.9	215.4 ± 26.9	31.0 (13.1; 48.8)	3.3 (−22.2; 28.9)
Mean daily variability (%)	5.6 ± 1.3	5.9 ± 1.3	0.3 (−1.2; 1.8)	5.3 ± 1.4	4.4 ± 1.4	−0.9 (−2.3; 0.5)	1.2 (−0.9; 3.3)
Days with variability ≥ 15% (<i>n</i>)	3.0 ± 3.0	5.5 ± 3.0	2.5 (−8.2; 5.8)	5.3 ± 3.2	5.0 ± 3.2	−0.3 (−3.6; 2.9)	2.8 (−1.8; 7.5)
Children ≥ 1 day per 14 days with variability ≥ 15% (%)	54.9 ± 17.6	54.9 ± 17.6	0.0 (−27.7; 27.7)	44.4 ± 18.8	30.1 ± 18.8	−14.3 (−41.3; 12.7)	14.3 (−24.3; 52.9)

^aMeans (95% C.I. limits) adjusted for age, gender, parents' level of education and eczema.^bAbsolute value = Year 2 − Year 1.

Reduction in formaldehyde concentration and asthma-related morbidity

In the intervention group, we found a significant relationship between the reduction in the concentration of formaldehyde and the prevalence of asthma symptoms

Table 5 Relationship between 50 % reduction in formaldehyde concentration and change in annual prevalence of asthma symptoms and care use among children of the intervention group^a

Variable	Change ^b	P-value
≥ 1 episode of wheezing	−14.8 (−28.6; −0.9)	0.037
Disturbed sleep	−15.7 (−36.0; 4.6)	0.130
Severe wheezing ^c	1.5 (−20.0; 23.1)	0.888
≥ 4 episodes of wheezing	−7.2 (−19.6; 5.3)	0.255
Effort wheezing	−9.1 (−22.4; 4.1)	0.173
Night cough	−20.4 (−35.7; −5.0)	0.010
Rhinitis	11.0 (−2.3; 24.3)	0.105
≥ 1 emergency room visit	−16.0 (−30.5; −1.5)	0.031
≥ 1 hospitalization	−7.9 (−20.6; 4.8)	0.218

^aAdjusted for age and eczema.^bThe values are estimated changes in percentage (95% C.I. limits) of children with symptoms or emergency care use during the year associated with a 50 % reduction of formaldehyde level from baseline.^cEpisode of wheezing with disturbed sleep (≥1 night/week) and/or disturbed speech.

and care use over a one-year period. The estimated effects of a 50% reduction in the mean indoor formaldehyde concentration are presented in Table 5. This level of reduction was found in 25.6% of the homes of the intervention group. The estimated decreases of the prevalence of wheezing, night coughing, and emergency visits for asthma vary between 15% and 20%. No significant relationship was observed in the control group.

Discussion

Overview

In the participant sample screened, 75% of homes did not meet minimum recommended ventilation guideline of 0.30 ACH even though two-thirds of the homes of our population study were equipped with a mechanical ventilation system compared with one-third of the households in Quebec City (Gilbert et al., 2006). The higher preponderance of ventilation system observed in this study is likely due to the parents of the asthmatic children being sensitized to the importance of

good indoor air quality in managing the asthma symptoms of their children. Our ventilation intervention has shown that the optimization of existing system or the addition of either an HRV or ERV is both a feasible and effective approach to increasing ventilation rates and improving air quality. The intervention on ventilation allowed 72% of the homes in the intervention group to successfully attain the nominal ventilation goal of 0.30 ACH, in comparison with 15% in the control group, suggesting no or limited contamination between groups in this unblinded trial. Considering the very low ventilation rates observed in the first quartile, we can presume that a much larger proportion of homes would have attained that goal if our target of increase had been higher than 0.15 ACH. We also showed that ERVs, through their semi-permeable transfer core, are effective at preventing excessive dryness when increasing ventilation rates in homes in fall and winter. Overall, relative humidity was significantly reduced in the homes of the intervention group relative to the control group. However, in a subgroup analysis, the homes receiving an HRV experienced an average reduction in relative humidity in the child's bedroom and the living room of 4.8% and 11.4%, respectively, while the homes receiving an ERV experienced an average increase in RH of 3.6% and 0.1% (data not shown). Contrary to popular perception, mechanical ventilation did not lower the whole house temperature which may increase the need for heating, a finding that was concordant with a prior study in Canada (Kovesi et al., 2009).

We demonstrated that improved ventilation had a decisive impact on the reduction in the concentration of formaldehyde in the home following the intervention. The reduction in formaldehyde concentrations in the homes may be explained by exhaust and dilution resulting from increased ventilation through the decrease in relative humidity. In the pre-intervention baseline in Year 1, 30% of the homes exceeded the formaldehyde guideline of $50 \mu\text{g}/\text{m}^3$. During the fall and winter following the intervention in Year 2, all homes in the intervention group met the formaldehyde guideline. This result is consistent with the results of the Gilbert et al. Quebec City study, which showed that the air change rate ensuring a formaldehyde concentration below Health Canada's guideline value of $50 \mu\text{g}/\text{m}^3$ in 95% of homes was 0.26 ACH based on the entire sample (Gilbert et al., 2008). This result is striking considering the Sherman and Hodgson's estimate that a 0.50 ACH in a typical North American home would provide 90% of homes with a formaldehyde concentration below $50 \mu\text{g}/\text{m}^3$ (Sherman and Hodgson, 2004). The levels of airborne mold spores and selected VOCs concentrations were significantly reduced in the homes of the intervention group compared with the control group. However, the concentrations of those contaminants were low at

baseline. There was no significant group difference in the proportions of homes between Year 1 and Year 2 exceeding the sensitization levels ($\mu\text{g}/\text{g}$) in child's mattress dust for HDM *Der f* 1, HDM *Der p* 1, cat *Fel d* 1, and dog *Can f* 1 allergens. The observed increase in NO_2 concentrations could potentially be explained by drawing in more polluted air from outdoors (Gilbert et al., 2006); however, outdoor measurements were not performed to be able to assess this. As observed in the study of Bornehag, phthalate concentrations in dust are higher in the well-ventilated homes (intervention group), but this relation is still unexplained (Bornehag et al., 2005a,b).

A comparison of the 5-month period in the fall and winter seasons from November to March of Year 1 and 2 revealed that the intervention on ventilation had no significant short-term impact on the frequency of asthma symptoms. However, when the entire 12-month period of Year 2 was compared with Year 1, the intervention was associated with a 22% and 20% greater reduction in the prevalence of wheezing and frequent (≥ 4) wheezing episodes, respectively, compared with controls. In a post hoc analysis, a significant reduction in the concentration of formaldehyde in the intervention group was associated with decreases in wheezing, as well as night coughing (Venn et al., 2003). Based on the European Respiratory Society (ERS) Task Force, wheezing episodes can be triggered or exacerbated by multiple environmental factors, including chemical contaminants (Brand et al., 2008). Currently, formaldehyde is recognized as the most consistently identified risk factor for respiratory and allergic problems in residential buildings (Mendell, 2007). Formaldehyde exposure is associated with irritation of the respiratory tract and asthma in children (Health Canada, 2006; U.S EPA, 2007). In young children, an increased risk of asthma has been associated with formaldehyde exposure above $60 \mu\text{g}/\text{m}^3$ (Krzyzanowski et al., 1990; Rumchev et al., 2002). The results of a systematic review suggest a 3% increase in the prevalence of childhood asthma per $10 \mu\text{g}/\text{m}^3$ increment of indoor formaldehyde concentration (McGwin et al., 2010). The present study confirmed an association between the degree of reduction in formaldehyde concentration and the reduction in wheezing illnesses.

Comparison with other studies

Very few randomized controlled intervention studies have been conducted to evaluate the environmental health impact of mechanical ventilation systems in the homes. The first study of 40 asthmatic adults in Southampton, UK, showed an association between heat recovery ventilators and a reduction in humidity, dust-mites, and *Der p* 1 concentrations, but no effect on clinical symptoms (Warner et al., 2000). A randomized double-blind placebo controlled study was

conducted more recently to measure the impact of heat recovery ventilators on dust-mites and respiratory function in 120 asthmatic adults (Wright et al., 2009). Results showed a significant decrease in relative humidity indoors and an improved mean evening PEFR. No significant change in *Der p* 1 levels was observed. Kovesi et al. conducted a randomized double-blind placebo controlled study in Nunavut to measure the impact of heat recovery ventilators on indoor air quality and respiratory symptoms in 51 young Inuit children from the general population (Kovesi et al., 2009). Results showed a significant decrease in CO₂ concentrations and relative humidity, as well as a progressive decline in reported wheezing 4 weeks after the intervention. The Inuit study population was much younger (mean age 26.8 months) than children in our study; they were exposed to environmental tobacco smoke and at high risk of developing lower respiratory tract infection (Kovesi et al., 2007). Thus, the initial decline in symptoms was most likely explained by a reduction in acute viral respiratory infections. Avoidance of allergen exposure may also explain a rapid decline, within 2 months, in the rate of respiratory symptoms in highly sensitized children (Morgan et al., 2004). However, it is a known fact that because of the climate, there is virtually no allergen dust-mite exposure in the Inuit population (Dotterud et al., 1997; Kovesi et al., 2006).

Strengths and limitations

The IVAIRE study has several strengths. Asthma in children is recognized as one of the top five priorities to be addressed and funded by health agencies in Canada (Leitch, 2007). The studied population was a high-risk group of children with asthma in that they had within the past year an asthma exacerbation requiring medical care (emergency visit, hospital admission, oral corticosteroids) and were cared at a tertiary care centre. Of interest, two-thirds of them lived in under ventilated homes. The development of field validated intervention strategies for controlling sources of pollutants and optimizing ventilation to improve indoor air quality is a priority under the Clean Air Regulatory Agenda (CARA) of Canada. A randomized controlled study design was used and the field study included comprehensive measurements of ventilation, indoor air quality, and health carried out by a multidisciplinary team. Environmental data collection covered three seasons per year including the entire heating season, particularly determinant for occupant exposure in cold weather climates. The retention rate was excellent with only one participant dropping out the study after randomization. The ventilation intervention was uniformly able to achieve the desired 0.15 ACH increase in ventilation. It intended to correct real-life situations using the optimal equipment, either an HRV or ERV,

selected to maintain adequate humidity levels in the homes. The use of ERVs was particularly effective in mitigating excessive dryness in the homes where increased ventilation would have likely led to excessive dehumidification. No adverse effect was reported by the participants.

We acknowledge the following limitations. First, about 50% of children who were recruited had been followed since one to 3 years, whereas about 50% were recruited at their first visit to the asthma clinic. We may presume that asthma might be more stable in the children who were followed since more than 1 year because pediatricians had more time to control symptoms using inhaled corticosteroid (ICS) preventive therapy in particular. Nevertheless, after randomization, the average length of medical follow-up at asthma clinic should be similar in the intervention and the control groups. The children of both groups experienced a clinically important decrease in symptoms, emergency visits, and hospitalizations that had not been anticipated by our sample size calculation, thus reducing our ability to detect a statistically significant group difference. ICS therapy represents a potential confounding factor, which was controlled by randomization. Indeed, there was no significant difference in medication utilization between the intervention and the control groups at baseline. In Table 2, the proportions of children taking ICS at baseline were 62.5% and 65% in the intervention and the control group, respectively. The proportions of children using short-acting beta-agonists as a reliever medication were 82.5% and 75%, respectively. Furthermore, the adjusted group difference including adjustment for ICS utilization was not significant with -0.5 ($-2.0; 0.9$) days with symptoms per 14 days (data not shown). Improvement of the number of days with symptoms observed in both groups was quite large. From 5.9 days (s.d. 4.86) and 5.0 days (s.d. 5.0) with symptoms over 14 days, it decreased of -1.5 days and -0.9 days in the intervention group and in the control group, respectively (Table 4). Asthma seems more severe in the children of the intervention group than in the control group. The number of days with relief medication and the proportion of children with >8 doses decreased significantly in the intervention group and remained unchanged in the control group during Year 2. Those decreases of relief medication utilization may be due globally to the comprehensive medical treatment given by asthma clinic and other potential factors related to the intervention. In a previous home-based environmental intervention study, a similar improvement in asthma symptoms has even been observed, which might be also attributable to the Hawthorne effect (observer effect) related to the number of contacts with each family in both groups during the study (Morgan et al., 2004). However, we do not have the data that would support these phenomena.

We had reached 75% of our target sample size of 60 children per group and 84% of children completed the 5-month diary, thus further reducing the power of the study. In retrospect, our sample size calculation was too optimistic. In our study, we presume that the intervention cannot plausibly increase the frequency of symptoms per 14 days in children. Two-tailed t-test is the usual recommended conservative measure. With a two-sided 5% significance test, a power of 80% and the same s.d., the estimated detectable reduction was 2.42 days with symptoms per 14-day period. Decrease of 2.4 days per 14 days was observed in the multifaceted home intervention study of Morgan et al. (2004) on control of house dust-mite and of environmental tobacco smoke in a very high-risk population. However, such a decrease was less plausible in this mono-faceted study, in which the intervention was limited to improvement of ventilation in the home and in which the concentrations of air contaminants were relatively low at baseline, except for formaldehyde.

As for our secondary outcome, we cannot exclude that the observed significant decrease in the prevalence of wheezing in the intervention group could be due to multiple comparisons, taking into account the first test performed to compare the number of days with symptoms, our primary outcome (Bender and Lange, 2001). Probability of the type I error (rejecting the null hypothesis although it is true) is increased to 10% instead of 5% for comparison of prevalence of wheezing in both groups. Special procedures for multiple tests adjustments are available, but the need for multiplicity adjustment for studying biologic relations is still debated (Rothman, 2014).

An electronic diary was not used rather than paper daily diaries because it was too costly and had potential disadvantages (Krishnan et al., 2012). Our main outcome was based on a diary developed *ad hoc* and similar to the one already used by the physicians of the asthma clinic. Although participants were not blinded in the intervention, there was no evidence of contamination between groups. Moreover, technicians followed a rigorous protocol to provide standardized unbiased information to all participants during the study, and environmental and clinical data were captured blind by two research assistants. For feasibility reasons related to costs and technical issues, we did not use a disabled ventilation system as a placebo in the control homes. Nevertheless, based on the Cochrane Collaboration, the beneficial placebo effect for parent-reported asthma symptoms, if it exists in our study, would have been small (RR: 0.93; 95% C.I.: 0.85–1.02) (Hróbjartsson and Gøtzsche, 2010).

In general, most of the single family homes of the enrolled children with asthma had good indoor air quality during the baseline period. Of interest, 67% had a pre-existing mechanical ventilation system; however, the ventilation rates were inadequate (under 0.30

ACH) in the majority of homes. This was likely due to a combination of improper equipment selection, installation, maintenance, and/or operation. One-third of the homes exceeded the Health Canada long-term indoor air quality guideline for formaldehyde during the fall and winter seasons at baseline. As children were selected solely based on exacerbation requiring medical care in the prior year and single home family, the observation that 75% of these houses failed to meet the ventilation status is of public health interest. Future study should aim for larger ventilation rates including 0.5 ACH to enhance change in environmental and health outcome. Small sample size and feasibility issues have not allowed us to cover that in our study.

Conclusion

In conclusion, improved ventilation rate in the homes of children with suboptimal asthma control was associated with a statistically significant reduction in relative humidity, several biologic and chemical contaminants. These changes notably included marked reduction in formaldehyde levels, with all intervention homes meeting the formaldehyde indoor air long-term recommended guideline during the fall and winter, which are periods with the highest exposure to indoor air contaminants. Following intervention, the proportion of the homes of the intervention group with ventilation rate ≥ 0.30 ACH increased from 5% to 72%. Improved ventilation rates had no statistically significant impact on the frequency of asthma and respiratory symptoms over the 5-month period but significantly reduced the proportion of children with any and those with frequent wheezing by 20% or more during the 12 months following intervention. A reduction in formaldehyde exposure appears as the most plausible factor explaining the decrease in wheezing in children living in the homes in which ventilation rate was improved. After controlling basic pollution sources, formaldehyde appears to be the most clinically relevant environmental factor to control in the home with asthmatic children through improvement of ventilation. Unfortunately, due to lack of power, this study cannot say if improved ventilation rate in the home affects daily symptoms of asthma or not during the fall and winter seasons following the intervention. However, it does indicate that a bigger study is needed because the effect size on daily symptoms 1/3 the size of medical treatment could be of clinically significant from a public health perspective,

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Competing financial interests declaration

The authors declare that they have no competing financial interests.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Summary list of measured environmental parameters and methods analysis.

Table S2. IVAIRE – Summary list of the interventions on the ventilation systems in the homes of the intervention group.

Data S1. Laboratory method for VOC analysis.

Data S2. Laboratory method for SVOC analysis.

Data S3. Standardized ISAAC questionnaire (IVAIRE French Canadian version) for 6/7 year olds on long-term prevalence of asthma and rhinitis.

Data S4. Validated Asthma Quiz on asthma control in children.

Data S5. Daily symptoms diary including medication utilization coupled with PEFr monitoring per 14 day period (French Canadian version).

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The IVAIRE Project - A Randomized Controlled Study of the Impact of Ventilation on Indoor Air Quality and the Respiratory Symptoms of Asthmatic Children in Single Family Homes

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Table S1 Summary list of measured environmental parameters and methods analysis

Parameter	Method of Analysis	Location of sampling	Season and duration of sampling
Ventilation Rate	Perfluorocarbon tracer gas technique (PFT)	Child's bedroom and living room	6-8 days integrated measurement during fall, winter and summer
	Sulfur hexafluoride (SF ₆) tracer gas decay	Child's bedroom	4-5 hour real-time measurement during fall and winter
Airtightness	Orifice blower door test	Main door of the house	Once each during fall/winter and during summer
Aldehydes/formaldehydes	Waters Sep-Pak XPOSure passive samplers	In the child's bedroom	6-8 days integrated measurement during fall, winter and summer
NO₂	Ogawa sampler followed by ion chromatography.	In the child's bedroom, playroom or family room	6-8 days integrated measurement fall, winter and summer
Temperature/Relative Humidity /CO₂	HOBO U12-013 data logger with a Vaisala GMW21 CO ₂ sensor.	In the child's bedroom, and playroom or family room or in the basement if the room is occupied	6-8 days measurement period, during fall, winter and summer
Volatile organic compounds (VOCs)	Passive samplers with Tenax TA 60/80 sorbent, then analyzed by thermal desorption and GC/MS.	In the child's bedroom	6-8 days measurement period, during fall, winter and summer
Fine particles (PM_{2.5})	Grimm 1.108 aerosol spectrometer (fine PM, 4-5 hrs).	In the child's bedroom	4-5 hrs sampling during fall and winter
Airborne Mould Spores	Air sampling with Staplex MAS-2 on DG 18 and MEA media.	In the child's bedroom, playroom or family room or in the basement if the room is occupied	10 minutes sampling during fall and winter
Semi-volatile Organic Compounds (SVOCs)	House dust sampled with a vacuum, extracted and analyzed by GC/MS.	In the child's bedroom	Sampled from 2 m ² area on floor during fall and winter
Allergens	Sieved dust samples analysed with ELISA assay for mite, dog and cat allergens.	In the child's bedroom	From mattress and carpets during fall, winter and summer
Building, ventilation characteristics and occupant behaviour.	Parental questionnaires on environment and home inspection	Whole home	During fall, winter and summer

Table S2 IVAIRE – Summary list of the interventions on the ventilation systems in the homes of the intervention group

Mechanical ventilation system (MVS) in place at baseline		Homes (n)
Yes		32
No		11
	Total	43
Types of Interventions		
In the 32 homes with an MVS		
Replacements		27
Improvements ¹		5
	Total	32
In the 11 homes without an MVS		
New ventilation system		6
New ventilation system coupled to pulsed air system		5
	Total	11
List of models intalled²		
AVS Solo 1.5		2
Constructo 1.0		18
Duo 1.4		8
Duo 1.9		6
Novofit 1.5		6
Novofit 2.0		1
Solo 1.5		2
	Total	43
Types of recovery ventilators		
HRV		24
ERV		19
	Total	43

¹ Improvements included, for instance, installation of recovery ventilators in series with a furnace, installation of controls, relocation of air vents, and others.

² All Venmar models installed – selection made by the ventilation task force based on the ventilation technical prescription, the contractor's usual practice and the consent from the owner.

Data S1. Laboratory method for VOC analysis.

The VOCs were then desorbed from the tubes with a flow of helium using a Gerstel TDS 3 thermal desorption system and focused on a cooled inlet at -90 °C. The thermal desorber temperature ramp was 60 °C min⁻¹ until 300 °C followed by a 5 min hold time. The compounds were then separated and detected on an Agilent 6890 GC-MSD operating in scan mode from m/z 35 to 300. The GC was equipped with Supelco SPB-624 column (30 m x 0.25 mm i.d. x 1.4 µm thickness) and the temperature program was 35 °C for 5 min followed by a 6 °C/min temperature ramp to 230 °C

Data S2. Laboratory method for SVOC analysis.

The dust samples were kept refrigerated at 4 °C until ready for analysis. Prior to analysis for SVOC's the dust samples were sieved then dissolved in 1.5 mL of a 1:1 solution of analytical grade cyclohexane and acetone. The samples were vortexed and then ultrasonicated at 45 °C for 30 minutes. The samples were centrifuged at 4500 rpm for 10 min and the supernatant extracted for analysis by gas chromatography and mass spectrometry. An Agilent 6890 gas chromatograph equipped with an Agilent DB5-MS column (30 m, 0.25 mm i.d., and 0.25 µm thick stationary phase) was used to separate the compounds. The temperature program consisted of a temperature ramp from 80 °C to 160 °C at 20 °C/min, followed by a 160 °C to 320 °C temperature ramp at 10 °C/min and a hold at 320 °C for 5 min. The analytes were identified and quantified on an Agilent 5973N MSD operating in single ion mode with an electron ionization voltage of 70 eV.

**ÉTUDE DES IMPACTS DE LA VENTILATION
SUR LA QUALITÉ DE L'AIR INTÉRIEUR
ET LA SANTÉ RESPIRATOIRE DES ENFANTS
SOUFFRANT DE SYMPTÔMES RELIÉS
À L'ASTHME DANS LES HABITATIONS RÉCENTES**

**SYMPTÔMES RESPIRATOIRES
ET ALLERGIQUES**

QUESTIONNAIRE AUX PARENTS

Merci de votre collaboration essentielle à la réussite de cette étude.

Institut national de santé publique du Québec

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Direction des risques biologiques,
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Québec (Québec) G1V 5B3
Téléphone : (418) 650-5115, poste 5229
Télécopieur : (418) 654-3144

N° de dossier :

N° de l'intervieweur :

Date de l'entrevue :

Instructions

À compléter par le parent.

La plupart des questions ont plusieurs choix de réponse possibles. Choisissez celle qui vous convient le mieux.

Répondez au meilleur de votre connaissance. Il n'y a pas de bonne ou de mauvaise réponse.

Donnez une seule réponse à chaque question, à moins d'indication contraire.

-
1. L'enfant a-t-il (elle) eu des sifflements dans la poitrine, à un moment quelconque, **au cours des 12 derniers mois** ?

Oui..... 1

Non..... 2

2. Combien de fois a-t-il (elle) eu ces crises de sifflements **au cours des 12 derniers mois** ?

1 à 3 fois..... 1

4 à 12 fois..... 2

Plus de 12 fois..... 3

3. **Au cours des 12 derniers mois**, combien de fois, en moyenne, son sommeil a-t-il été gêné par ces crises de sifflements ?

Jamais..... 1

Moins d'une nuit par semaine..... 2

Une ou plusieurs nuits par semaine 3

4. **Au cours des 12 derniers mois**, ces crises de sifflements ont-elles été si graves qu'elles ont limité son discours à un ou deux mots maximum entre deux respirations ?

Oui 1

Non..... 2

5. L'enfant a-t-il (elle) **déjà** eu des crises d'asthme ?

Oui 1

Non..... 2

6. **Au cours des 12 derniers mois**, sa poitrine a-t-elle produit des sifflements pendant ou après un effort intense ?

Oui 1

Non..... 2

7. **Au cours des 12 derniers mois**, l'enfant a-t-il (elle) eu une toux sèche la nuit qui n'était pas due à un rhume ou à une infection pulmonaire ?

Oui 1

Non..... 2

8. **Au cours des 12 derniers mois**, a-t-il (elle) eu des éternuements, le nez qui coule ou le nez bouché **quand il (elle) n'était pas** enrhumé(e) ou grippé(e) ?

Oui 1

Non..... 2

9. **Au cours des 12 derniers mois**, est-ce que ces troubles du nez étaient accompagnés de larmoiements et de démangeaisons des yeux ?

Oui 1

Non..... 2

10. Pendant lequel (lesquels) de ces **12 derniers mois** a-t-il(elle) eu ces troubles du nez ?

➤ *Indiquez plusieurs mois s'il y a lieu.*

Janvier 01

Mai 05

Septembre..... 09

Février 02

Juin..... 06

Octobre 10

Mars 03

Juillet 07

Novembre..... 11

Avril 04

Août..... 08

Décembre..... 12

11. **Au cours des 12 derniers mois**, ces troubles du nez ont-ils gêné ses activités quotidiennes ?

Pas du tout..... 1
Un peu 2
Modérément..... 3
Beaucoup..... 4

12. L'enfant a-t-il(elle) **déjà** eu le rhume des foins ?

Oui 1
Non..... 2

13. Au cours des 12 derniers mois, est-ce que l'enfant a été hospitalisé?

Oui 1
Non..... 2

Si oui, précisez

Date (s) _____

Hôpital (aux) _____

Diagnostic (s) _____

14. Au cours des 12 derniers mois, est-ce que l'enfant est allé à l'urgence d'un hôpital?

Oui 1
Non..... 2

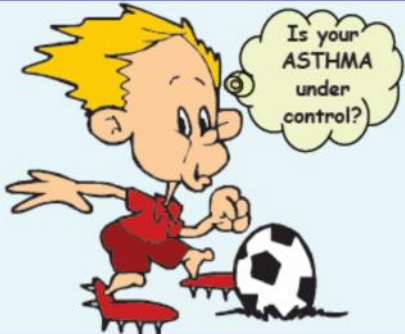
Si oui, précisez

Date (s) _____

Hôpital (aux) _____

Diagnostic (s) _____

Data S4. Validated Asthma Quiz on asthma control in children



Is your
ASTHMA
under
control?

ASTHMA QUIZ FOR KIDZ

- 
 1. Did you cough, wheeze, or have a hard time breathing **4 or more days** out of the **last 7 days**? ☐ Yes ☐ No
- 
 2. Did you wake up at night because you were coughing, or wheezing, or having a hard time breathing **1 or more times** in the **last 7 days**? ☐ Yes ☐ No
- 
 3. Did you use your blue puffer or pump **4 or more times** in the **last 7 days**? ☐ Yes ☐ No
- 
 4. In the **last 7 days**, did you do less exercise or sports because it was making you cough, wheeze, or you were having a hard time breathing? ☐ Yes ☐ No
- 
 5. In the **last 30 days**, did you miss school or regular activities because you were coughing, wheezing, or having a hard time breathing? ☐ Yes ☐ No
- 
 6. In the **last 30 days**, did you go to a clinic or a hospital without an appointment because you were coughing, wheezing, or having a hard time breathing? ☐ Yes ☐ No

How many **YES** balls did you let in? 

If you let in **2 or more YES** balls, your asthma is not well controlled.
Talk to your mom and dad about seeing a doctor.
Let your doctor be your asthma coach!

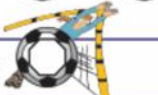
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Est-ce que
ton ASTHME
est sous
contrôle?

QUIZ sur L'ASTHME pour les JEUNES

- 
 1. As-tu toussé, eu une respiration sifflante, ou de la difficulté à respirer **4 jours ou plus** au cours des **7 derniers jours**? ☐ Oui ☐ Non
- 
 2. As-tu été réveillé la nuit par une toux ou une respiration sifflante ou de la difficulté à respirer **1 fois ou plus** au cours des **7 derniers jours**? ☐ Oui ☐ Non
- 
 3. As-tu utilisé ta pompe bleue **4 fois ou plus** au cours des **7 derniers jours**? ☐ Oui ☐ Non
- 
 4. Au cours des **7 derniers jours**, as-tu été limité dans tes exercices ou activités sportives en raison d'une toux, d'une respiration sifflante ou d'une difficulté à respirer? ☐ Oui ☐ Non
- 
 5. Au cours des **30 derniers jours**, as-tu été absent de l'école ou de tes activités habituelles en raison d'une toux, d'une respiration sifflante ou d'une difficulté à respirer? ☐ Oui ☐ Non
- 
 6. Au cours des **30 derniers jours**, as-tu visité un docteur dans une clinique sans rendez-vous ou une salle d'urgence en raison d'une toux, d'une respiration sifflante ou d'une difficulté à respirer? ☐ Oui ☐ Non

Combien de ballons **OUI** as-tu laissé entrer? 

Si tu as laissé entrer **2 ballons OUI** ou plus, ton asthme n'est pas bien contrôlé.
Demande à ta mère et ton père de t'amener chez le docteur.
Laisse ton docteur t'aider à atteindre ton but!

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JOURNAL QUOTIDIEN DES SYMPTÔMES

(Data S5. Daily symptoms diary (French Canadian version))

MOIS : NOVEMBRE

ANNÉE : 2008

Ma meilleure valeur au DEP : _____

DÉBIT EXPIRATOIRE DE POINTE (DEP)

Au réveil : **point bleu** ----- Au coucher : **point rouge**

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
HEURE	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
550																														
500																														
450																														
400																														
350																														
300																														
250																														
225																														
200																														
175																														
150																														
125																														
100																														
75																														

SYMPTÔMES

0=absent 1=léger 2=modéré 3=sévère

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Toux																															
Sifflement																															
Tirage																															
Sommeil perturbé																															
État grippal / rhume																															
Essoufflement																															
Autre :																															

MÉDICAMENTS

Indiquer le nombre de bouffées (puffs) ou comprimés pris dans la journée

Pour utiliser le débitmètre de pointe (DEP) :

- ❶ Je mets le curseur jaune à zéro, c'est-à-dire dans le losange «reset».
- ❷ Je tiens le débitmètre à l'horizontal.
- ❸ Je remplis mes poumons au maximum.
- ❹ J'introduis l'embout dans ma bouche et je serre les lèvres autour.
- ❺ J'expire le plus **fort** et le plus **vite** possible.
- ❻ Je fais cet exercice **3 fois** et je note la lecture la plus **élevée** dans le graphique (par un point bleu le matin et un point rouge le soir).
- ❼ Faire les mesures le matin (au réveil) et le soir (au coucher), toujours avant le traitement.
- ❽ Ranger l'appareil dans sa boîte ou dans un sac plastique.

Pour entretenir le débitmètre de pointe (DEP) :

Laver le débitmètre une fois par semaine :

- ❶ Agiter doucement le DEP dans une solution d'eau tiède et de savon doux.
- ❷ Rincer-le en douceur et à fond.
- ❸ Laisser sécher à l'air libre.

