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# Health in occupants of energy efficient new homes

**Abstract** A prospective telephone-administered questionnaire study in new home occupants compared general and respiratory health at occupancy and 1 year later in two groups. The test group or cases, was 52 R-2000™ homes (128 occupants) built to preset and certified criteria for energy efficient ventilation and construction practices. The control group were 53 new homes (149 occupants) built in the same year in the same geographic area and price range. Analyzed by household, case occupants' summative symptom scores improved significantly over the year of occupancy (Wilcoxon rank sum test, $P < 0.006$). Analysis of variance of individuals' total symptom scores showed a significant effect of the type of house ($P < 0.0001$), with lower change of scores in case buildings, but not of age or sex. In comparison with control homes, occupants of case homes reported more improvement in throat irritation ($P < 0.004$), cough ($P < 0.002$), fatigue ($P < 0.009$) and irritability ($P < 0.002$) with the main change in symptom category being from 'sometimes' to 'never'. Further extension of this pilot study is required to determine if these perceived health benefits are reproducible and/or relate to objective indoor air quality measures.

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**Practical Implications**
New occupants of energy efficient homes with heat recovery ventilators report improvement over 1 year in the symptoms of throat irritation, cough, fatigue, and irritability in comparison with control new home occupants. If this pilot study is reproducible and shown to relate to indoor air quality, prospective new home buyers may be interested in obtaining this health information prior to decision making.

## Introduction

Data from the Canadian Human Activity Pattern survey indicates that, on the average, Canadians spend about 89% of their time indoors overall and 66% of their time indoors at home (Leech et al., 1996). It would not, therefore, be surprising if housing stock, through its effects on indoor air quality, might have an effect on general and respiratory health. Since 1982, the R-2000™ Program has been developed by the Government of Canada. The primary criterion for R-2000™ certification is a tight building envelope with mechanical ventilation by a heat recovery ventilator (HRV). The builders are specifically trained and certified; the plans and construction of each home are evaluated and inspected, and completed houses are evaluated for air tightness before final certification (Canadian Home Builders' Association, 1994). Concerns have arisen regarding humidity, indoor air quality and potentially occupant health status in such homes. However, when the ventilation system is properly run and maintained, in combination with the program's mandated use of materials with less potential for volatile emission, indoor air quality could be better in R-2000™ homes than in other comparable new homes (Fletcher et al., 1996; Harving et al., 1994a,b). The purpose of this pilot study was to examine reported changes in health status by questionnaire in occupants of case homes at about 1 year after occupancy in comparison with health status in the year before occupancy and to control new home occupants' reported health changes over the same period of time.

## Methods

Consecutive registrants with the cases program were identified in 1997 and 1998 in New Brunswick and Nova Scotia, Canada. Control new homes were identified in the same geographic areas through the respective provincial new home warranty programs.

One adult occupant was interviewed by telephone, answering for all family members regarding the home and all occupants' health characteristics in the year prior to the interview. The baseline interview was held within 3 months of registration in the program; the follow-up interview was held 1 year later. The health questions related to symptoms in the year prior to occupancy on a range of general and respiratory symptoms, diagnosis of asthma, chronic obstructive lung disease (COPD) or heart condition, and medication use. At follow-up, the same questions were repeated, *without* reference to a *change* in symptoms since occupancy but with reference to the period of the first year of occupancy. Each symptom was graded by its frequency (never, sometimes, often, or always were scored 1–4, respectively).

Both case and control interviewees were informed in a general sense that the interview was about new homes and occupant health. Interviewers were not blinded to the case/control status of the household but were blinded to the baseline health responses when administering the follow-up interview.

### Data analysis

Frequency of baseline characteristics of households were compared between case and control new homes by $\chi^2$ test.

A symptom change score was calculated by symptom and as a summary change score. Thus, if a subject reported often having a runny nose in the prior year at baseline and never having a runny nose in the intervening year at follow-up, his symptom change score for 'runny nose' would be 2–0 = 2. Similarly, if 'never' went to 'often' the change score would be minus 2. His total symptom change score was calculated by adding all the scores for all his symptoms into one sum. A summary score of symptoms for an entire household was calculated by adding all the total scores for all household occupants at either point in time.

First, the symptom results data were examined by household. The summary score of symptoms for the entire household at baseline was compared with 1 year later by Wilcoxon rank sum test. A similar summary score for each control home was weighted by the number of family members per household and compared with the case homes similarly weighted.

Secondly, the data were examined by individuals: the total symptom change scores over the year were analyzed in an analysis of variance examining for the effect of age, sex, and case versus control home status.

Thirdly, the change scores were examined by symptom and compared between case and control new homes by two-tailed unpaired *t*-test.

For all analyses, a difference was considered to be of statistical significance when the probability was $<0.01$ because of the multiple comparisons being made.

## Results

Baseline and follow-up data after 1 year are available in 52 case new homes and 53 control new homes from New Brunswick (65%) and Nova Scotia (35%). In consecutive case occupants this represents an 83% response rate. Overall, five homes declined to participate and 16 could not be contacted after multiple attempts either at baseline or at follow-up. A similar response rate (79%) was obtained in control homes.

### Occupants' characteristics

There were 147 occupants in the 52 case homes at baseline and 146 occupants at follow-up ranging from one to five occupants per home. Due to changes in household make-up (principally the departure of older children and birth of new children) a total of 128 respondents had both a baseline and follow-up data in the case homes. Sixty-two of these respondents were male. The 53 control new homes had 165 occupants at baseline and 166 occupants at follow-up ranging from 1 to 6 occupants per home. Following a year's changes in household composition, a total of 149 individuals in the control homes had completed data to compare follow-up with baseline symptomatology. Seventy-three of these respondents were male.

Only one case home and no control new homes' occupants had previously occupied an R-2000™ home. Data from this family were not included.

Using a $P < 0.01$ from a simple $\chi^2$ test, the case occupants had a significantly greater number of respondents reporting that the following factors were important to the purchase of their house: style of house ($<0.01$), energy efficient feature ($<0.001$), and dampness control ($<0.01$). Size of house ($<0.1$), location of house ($<0.10$), resale value ($<0.10$), and indoor air quality ($<0.05$) were not viewed differently by case and control new home occupants when asked about their motivations in buying this particular house.

The variables used to assess socioeconomic status in this analysis were: education level, working status and gross annual household income (Table 1). Most of the new home buyers in both groups had a total family income of less than $100,000/year (Canadian). Case new home owners came more often from a community college/technical college background ($P < 0.01$) and more were retired. The retired couples were less likely to have children at home; hence the lower total number of occupants in the case households, and the differing age distribution between the two groups (Table 2).

At baseline, the sex, age, and health status of case occupants and control new home occupants is shown in Table 2. Control new homes were significantly more likely to have at least one current smoker. There were no significant differences between case and control

**Table 1** Education, working status and income

| | Case owners | | Control new home owners | |
|---|---|---|---|---|
| | Respondent (%) | Spouse (%) | Respondent (%) | Spouse (%) |
| Education level | | | | |
| Grade School | – | 2 | 8 | 9 |
| High School | 20 | 30 | 36 | 36 |
| Community/Technical College | 62 | 44 | 43 | 36 |
| Bachelor's Degree | 6 | 13 | 9 | 20 |
| Masters or PhD | 12 | 11 | 4 | – |
| Working status | | | | |
| Full-time | 50 | 68 | 57 | 69 |
| Part-time | 10 | 4 | 13 | 7 |
| Homemaker | 6 | 4 | 13 | 11 |
| Unemployed/Laid off | 8 | 4 | 2 | 2 |
| Retired | 27 | 19 | 15 | 11 |
| Annual household income group | | | | |
| Under $50,000 | 32 | | 40 | |
| $50,000–$100,000 | 57 | | 51 | |
| Over $100,000 | 11 | | 9 | |

**Table 2** Occupant[a] and housing baseline characteristics

| | Case new home owners | Control new home owners | $P^b$ |
|---|---|---|---|
| Sex: male | 48 | 49 | ns |
| Age (years) | | | |
| 0–17 | 26 | 37 | < 0.05 |
| 18–59 | 59 | 59 | |
| 60+ | 15 | 4 | < 0.05 |
| Hay fever, allergies | 58 | 49 | < 0.1 |
| Doctor diagnosed asthma (% houses with at least one asthmatic) | 12 | 23 | < 0.1 |
| Chronic bronchitis/emphysema | 4 | 6 | < 0.1 |
| Heart disease | 4 | 2 | < 0.1 |
| At least one current smoker | 14 | 38 | < 0.001 |
| Pets indoors | 50 | 60 | < 0.1 |
| Home heating | | | |
| Electric | 42 | 64 | < 0.001 |
| Central air furnace | 10 | 11 | |
| Combination | | | |
| Electric/woodstove/fireplace | 21 | 6 | < 0.05 |

Health characteristics (percentage of homes with at least one affected member).
[a] Based on occupants who had both baseline and follow-up questionnaires completed.
[b] $\chi^2$ statistic, two-tailed test.

homes with regard to the health of the occupants (allergy, hay fever, and asthma).

Factors known to adversely influence indoor air quality are also outlined in Table 2. Control homes had a higher percentage with at least one smoker in the household, and they had, although not significantly, more cats or dogs. Besides these indoor sources of contamination, ventilation and ventilation practices are also important influences on indoor air quality.

Although all R-2000$^{TM}$ homes are required to have an HRV, 10% of case respondents did not realize they had an HRV. In the remainder, only 78% reported understanding its operation. Only 76% operated the HRV throughout the winter and 58% throughout the summer. Fewer control homes reported owning an HRV (62%) and of these only 73% reported understanding its use. Less than 25% of all the homes had air conditioning.

**Table 3** Summative symptom change scores[a]

| | Case new homes | Control new homes |
|---|---|---|
| Number of houses | 52 | 53 |
| Highest score | +57 | +36 |
| Average score | +6.23 ± 1.7 s.d. | −0.45 ± 1.7 s.d. |
| Lowest score | −21 | −43 |
| No change | 6% | 13% |
| Worse score | 19% | 49% |

[a] Unweighted sum of symptom change scores for all members of each household. A positive change indicates movement to a better symptom category.

When the data were analyzed by household, the Wilcoxon rank sum test demonstrated significantly improved cumulative symptom scores in case households after 1 year occupancy ($P < 0.01$) compared with the year prior to occupancy. Table 3 demonstrates that, in general, the case households reported an improved score although some did report a worse overall weighted household score after 1 year. By contrast about half the scores were better and half were worse in the control new home occupants, ($P$, non-significant). On the average the family weighted symptom score difference in the case homes after 1 year was much greater than the difference in the control new homes.

When the data was analyzed by individuals, a multivariate analysis of factors affecting individuals' change in symptom scores showed that age and sex were non-significant but the type of house was significant ($P < 0.001$, $\Delta r^2 = 7\%$). On the possibility that some constellation of symptoms was affecting overall results, the multivariate analysis was repeated for summative change in symptoms related to the upper respiratory system, to the lower respiratory system and to the central nervous system (Table 4). It appears that age has a greater effect on upper respiratory symptoms (possibly an effect of colds in children) but for the other two symptom subgroupings, the house effect persisted.

**Table 4** Results of analysis of variance: total symptom scores and subgroups of symptom scores

| | '$P$' value for | | |
|---|---|---|---|
| Symptom score change | Housing stock[a] | Age | Sex |
| All symptoms | < 0.0001 | 0.10 | 0.13 |
| Upper respiratory symptoms (runny nose, blocked nose, sneezing, throat irritation) | 0.35 | 0.007 | 0.82 |
| Lower respiratory symptoms (cough, wheeze) | < 0.0001 | 0.63 | 0.475 |
| CNS symptoms (headache, fatigue, difficulty concentrating, irritability) | < 0.0001 | 0.973 | 0.327 |

[a] Case vs. control new home.

**Table 5** Changes in symptoms: case vs. control new home occupants (percentage of households with less symptoms summed over family members)

| Symptom | Percentage of households with symptom improvement | | Significance level (*P*) |
|---|---|---|---|
| | Case | Conventional | |
| Runny nose | 28 | 16 | 0.01 |
| Blocked nose | 23 | 18 | 0.25 |
| Sneezing | 28 | 16 | 0.02 |
| Throat irritation | 31 | 17 | 0.004 |
| Cough | 36 | 20 | 0.002 |
| Wheeze | 13 | 7 | 0.08 |
| Headache | 27 | 18 | 0.07 |
| Fatigue | 37 | 23 | 0.009 |
| Difficulty concentrating | 18 | 14 | 0.28 |
| Irritability | 39 | 22 | 0.002 |
| Dry skin | 25 | 18 | 0.11 |
| Nausea | 13 | 10 | 0.37 |
| Diarrhea | 16 | 18 | 0.59 |

When the data was analyzed by each symptom score change and compared between case and control new homes, throat irritation ($P < 0.004$), cough ($P < 0.002$), fatigue ($P < 0.009$) and irritability ($P < 0.002$) were significantly more likely to improve in case occupants than in control new home occupants (Table 5). In symptoms unlikely to be related to indoor air there was clearly no significant difference (nausea $P = 0.37$, diarrhea $P = 0.59$), while in some other respiratory symptoms there was a trend towards a difference in case over control homes (runny nose $P = 0.01$, sneezing $P = 0.02$, wheeze $P = 0.08$, not significant at the $< 0.01$ level). The main changes in symptom scores were from 'sometimes' to 'never'.

With regards to asthma, only three case occupants reported asthma both at baseline and at follow-up. Two of these three asthmatics reported improvement (by one category) in cough and wheeze over the 1-year period; and one reported no change. Four further individuals were reported to have asthma only on follow-up indicating it had been diagnosed in the intervening year. In the control new homes 14 individuals reported asthma both at baseline and follow-up. Three individuals were reported to have asthma only on follow-up. One of the 14 was worse with respect to cough and wheeze over this year, four remained the same and nine had reported improvement (by one or two categories).

## Discussion

This study suggests that occupants of case homes perceive a health benefit over 1 year of occupancy. The comparison with other control home occupants in the same region indicates that these results are unlikely to be due to regression to the mean or to new home occupancy. Further, this benefit was not seen in symptoms unlikely to be related to air quality, such as nausea or diarrhea. The respiratory symptoms chosen are the 'usual suspects' in indoor air quality assessments but in developing symptom scores it is not possible to say that symptoms are of equal importance or that the frequency of symptoms as graded are linear. Hence, score changes for individual symptoms were also compared. Some of the differences seen may relate to the fact that the control new home occupants differ from the case occupants in that there are higher baseline prevalences of smoking and asthma although lower rates of hay fever and allergies. Numbers of asthmatics are too few to draw conclusions.

What we are unable to exclude is the possibility that having paid a small premium to purchase the case home, the occupant answering the questionnaire for the family simply believes the air is indeed better and health is improved. The questionnaire methodology attempted to minimize this possibility by asking each time regarding symptoms in the past year, i.e. specifically *not* inquiring about a change in symptomatology. Respondents were not reminded of their previous year's answers, nor were the interviewers aware of the previous year's answers.

The results of studies of mechanical ventilation and dust mite concentrations in houses have been mixed. Work in Denmark has shown that energy efficient houses have lower humidity and house-dust mite concentrations when they have mechanical exhaust and supply ventilation (Harving et al., 1994a,b). In England a combination of mechanical ventilation and HEPA vacuuming was found to decrease dust mite concentration, but there was no effect on symptoms or measured airway hyperreactivity (Fletcher et al., 1996). In a second English study dust mites were not shown to be decreased at 3 and 12 months in 18 houses with mechanical ventilation albeit when the relative humidity still remained at 60% (Stephen et al., 1997). The question arose therefore whether warmer climate and higher humidity levels might overwhelm the ability of housing stock to improve human health through lowering dust mite concentrations.

In Sweden, 30 mechanically ventilated energy efficient homes studied after 5 and 15 months were shown to have decreased house-dust mite concentrations (Warner et al., 2000). Subsequently, 14 asthmatics in these houses were shown to have decreased medication use and symptom scores over the same time periods (Wickman et al., 1994). Each of these studies focused on dust mite control as the principal benefit but humidity control may also influence mold concentrations. If there is indeed a health benefit to case homes the most likely mechanism is through control of dampness, which has been shown to affect symptoms in occupants (Bornehag et al., 2001; Platt et al., 1989).

Although energy efficient mechanical ventilation using a heat recovery ventilator is the primary characteristic of case homes it is clear that not all homeowners were aware of this unit or its optimal use. At the same time some control new homes also had HRV's albeit without the other building materials and practices demanded of case homes. There is nothing in these results that would suggest a poorer health quality in the tightly enveloped energy efficient house even when occupants do not completely understand their ventilation systems.

Further study is needed to correlate perceived improvements in health symptoms with indoor air quality measurements in case homes and to see if similar findings will be seen in R-2000™ home occupants in other non-Maritime regions. If confirmed, the results will add further evidence that homes having a mechanical ventilation system, and tight envelope may be beneficial to the quality of life in normal occupants.

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