The Role of Ventilation
15th AIVC Conference, Buxton, Great Britain
27-30 September 1994

Predicted and Measured Air Change Rates in Houses with Predictions of Occupant IAQ Comfort

T Hamlin* W Pushka**

* Buildings Group, Energy Efficiency Division
CANMET/NRCCan, Ottawa, Canada

** Research Division, Canada Mortgage and Housing Corp, Ottawa, Canada

Abstract

The purpose of this study was to test an Indoor Air Quality model on a variety of Canadian homes, and use this model to determine the optimal ventilation levels necessary to provide appropriate comfort levels.

The Indoor Air Quality model tested (the AQ1 program), was a single zone hour-by-hour model of air leakage, mechanical ventilation and pollutant concentration. Measured weekly air change rates were compared to the model's predicted rates, and sensitivity analysis' performed on a number of inputs. The model was exercised under a number of different conditions, and its limitations and reliability were investigated.

The AQ1 model was then applied to some current Canadian household characteristics. The relationship between air tightness and carbon dioxide concentrations in typical Canadian homes was calculated, and the ventilation requirements to provide a reasonable level of comfort in Canadian homes was estimated using carbon dioxide concentration as an indicator.

The AQ1 Model

The AQ1 program was designed to provide a quick algorithm with relatively few inputs, that would accurately describe hourly ventilation/infiltration rates and pollutant concentrations. The model uses a single zone method, whole building airtightness, hourly weather data and apparent pollutant source strengths to model indoor air quality. The program uses the AIM-2 infiltration model by Walker and Wilson to calculate natural infiltration (4), the fan model by Palmiter to calculate fan/air leakage interactions, and a pollutant concentration method as developed by Palmiter and Bond (7). A minimum temperature difference of two degrees was assumed to always exist during heating seasons to account for solar and internal gains. The stack effect pressure therefore can only go to zero for a house in airconditioning mode.

The pollutant model calculates concentration in accordance with the following equations. The effect of pollutant absorption and reemission is not accomodated, however, since the source strengths used are “apparent source strengths”, the predicted concentrations will be correct for the same time base as the measurements. The apparent source strength is measured by taking simultaneous concentration and air change rate measurements. The equation used to calculate pollutant concentrations where the air-change rate is greater than 0.0001 is:

$$C_1 = C_0\, e^{-at} + S(1-e^{-at})/f$$

and

$$C_1 = C_0\, e^{-at} + S(1-a(0.5 + a/6))/V$$

if it is less.The average concentration for an hour is then;

$$C_{av} = (C_0-C_1)/a + S/f$$

if the air-change rate is greater than 0.0001/hr, and

$$C_{av} = (C_0+C_1)/2$$

if it is less. Thusly the concentration does not blow up severely at low air change rates.

Where C_1 is the new concentration (ppm).
C_0 is the original concentration (ppm).
a is the air change rate (h^{-1}).
t is time (hours).
S is the apparent pollutant emission rate (mL/h).
f is the flow rate (m^3/h).
V is the house volume (m^3).

The apparent pollutant emission rate is measured using simultaneous pollutant concentration and air change rate measurements. This apparent emission rate, therefore avoids the need to model absorption of non-emitting surfaces. The critical level of analysis was considered to be the concentration that occupants are exposed to.

The model simulates the control of mechanical ventilation, based on a schedule or the sensing of indoor/outdoor temperature differentials. This feature could also be used to simulate outdoor temperature controlledventilation or the opening of windows on a warm day. Imbalanced mechanical ventilation affects envelope presurres and this fan interaction effect of reducing air leakage is modelled.

Methodology

A total of 81 houses were chosen from 3 different studies (3), (5), and (6). The purpose of these studies varied from testing for VOCs (volatile organic compounds) to general indoor air quality. There was sufficient information on 81 of the houses to test the ventilation/infiltration aspects of the AQ1 model. House measurements had been taken for week long periods in January to April in 10 different cities across Canada.

An initial simulation was performed and after discounting for outliers, an adjusted R-squared value between expected and known PFT was determined. Sensitivity analysis and levels of error were determined for a number of variables, including wind effects, building altitude, set points, house heights and flue heights.

Since the data being tested had been gathered for purposes other than testing the AQ1 model, there were a number of uncontrolled factors contained in the measured data. Specifically, the air change rates would have changed due to the opening of windows on warm days, the opening of doors as people entered and exited the homes, the use of fireplaces, etc. It was felt that the largest variation would be due to the opening of windows on warm days, therefore, additional simulations were conducted using outdoor temperature controlled ventilation on the model to simulate this behaviour.

Using current Canadian housing characteristics, the AQ1 model was used to determine the relationship between air tightness and Carbon dioxide concentrations. House occupancies ranged from 1 to 6 people (within two standard deviations) and house sizes ranged from 300 to 800 m^2. Using the American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) recommended 1000 ppm as a maximum concentration to maintain a reasonable 'comfort' level over time, minimum ventilation requirements were determined for the various occupancy and house size ranges.

Discussion and Results

The refined simulation involved 80 houses. Opening of windows was simulated with an air change rate of 500m^3/h when the differential between the outdoor and indoor temperatures was less than 5 Celsius. See Graph #1. The inverse airchange rate or turnover times predicted by the model were integrated over the measurement period in order to make the results comparable. Outliers were removed as it was not possible to verify the suspect model input parameters, leaving 72 houses. The standard error of estimate between the calculated and measured PFT values was found to be 0.1. This level of error is smaller than a the common ventilation rate target of one third air change per hour. It should also be remembered that the behaviour of the inhabitants is not known in the houses, therefore increasing the expected variance in the outcome.

Error levels were compared against different variables. It was found that a relationship existed between the level of error and wind speed. See Graph #2. It appears that the AQ1 model begins to break down at high wind speeds. However, with only five houses experiencing high wind speeds, a definitive conclusion cannot be made. This breakdown was expected in that local envelope pressures are highly variable due to wind turbulence, building shape, etc and local terrain shielding could also be highly variable.

Sensitivity analyses were conducted on a number of inputs. These included building height, flue height, heating set points, cooling set points, and elevation above sea level. It was found that 30% changes in these variables had less than a 10% change in the air change results.

The AQ1 model was then applied to some current Canadian household characteristics. The relationship between building leakage and carbon dioxide concentrations on a seasonal basis is described in Graph #3. In typical Canadian climate, the homes would not be heated from May to September. During this period the occupants would have the option of opening their windows to ventilate their homes, without affecting their heating costs. In the months outside of this period, the highest pollution concentration levels were found in the month of October.

ASHRAE recommends that in order to maintain reasonable comfort, carbon dioxide levels not exceed an average 1000 ppm. Using October as the worst case period, and with a continuous occupancy of three people, the number of hours in which a group of houses exceeded the 1000 ppm target in the month were calculated. The data was obtained from (1). Averages of building heights and air-tightness exponents were used for four age groups in three regions. The 50th, 75th and 90th percentile results were used. See Graph #4.

Conclusions

The AQ1 model was found to be reasonably accurate in determining the ventilation/infiltration levels in an average home. The standard error of estimate between the calculated and measured weekly airchange rates was found to be 0.1. This level of error is smaller than a theoretical target of 0.33 ach.

Houses in British Columbia are still very loose. However, recently built houses in Ontario and the Prairies have shown considerable increases in their air-tightness. Some of these houses would require mechanical ventilation in the spring and fall to keep carbon dioxide levels in a comfortable range.

References

(1) Cooper, K., Moffatt, P., Palmiter, L., "Indoor Air Quality Analysis for Detached Residences", CMHC research report, Ottawa, Canada, July 1992.

(2) Hamlin, T., Cooper, K., "Ventilation for Energy Efficiency and Optimum Indoor Air Quality", 13th AIVC Conference, Nice, France, September 1992.

(3) Hamlin, T., Forman, J., Lubun, M., "Ventilation and Airtightness in New, Detached Canadian Housing", ASHRAE Symposium paper, Indianapolis, U.S.A., June 1991.

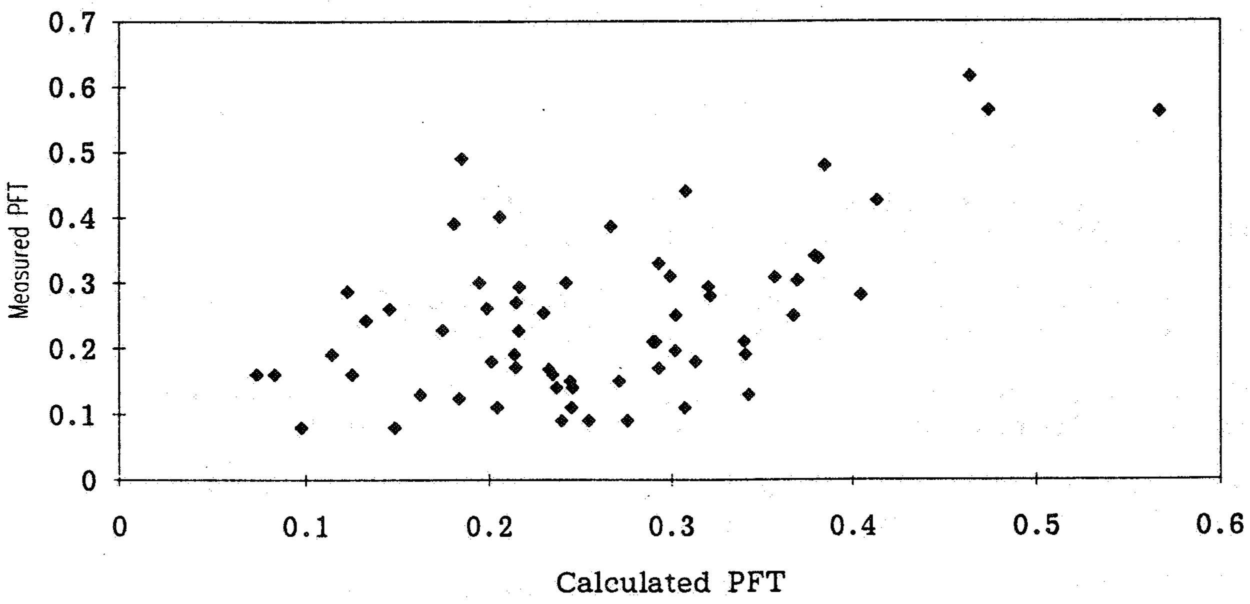
(4) Walker, I.S., Wilson, D.J., "The Alberta Air Infiltration Model AIM-2", University of Alberta, Dept. of Mech. Eng. Report 71, Edmonton, Canada, January 1990.

(5) Dumont, R., Snodgrass, L., "Volatile Organic Compound Survey and Summarization of Results", Saskatchewan Research Council, Saskatoon, Canada, January 1992.

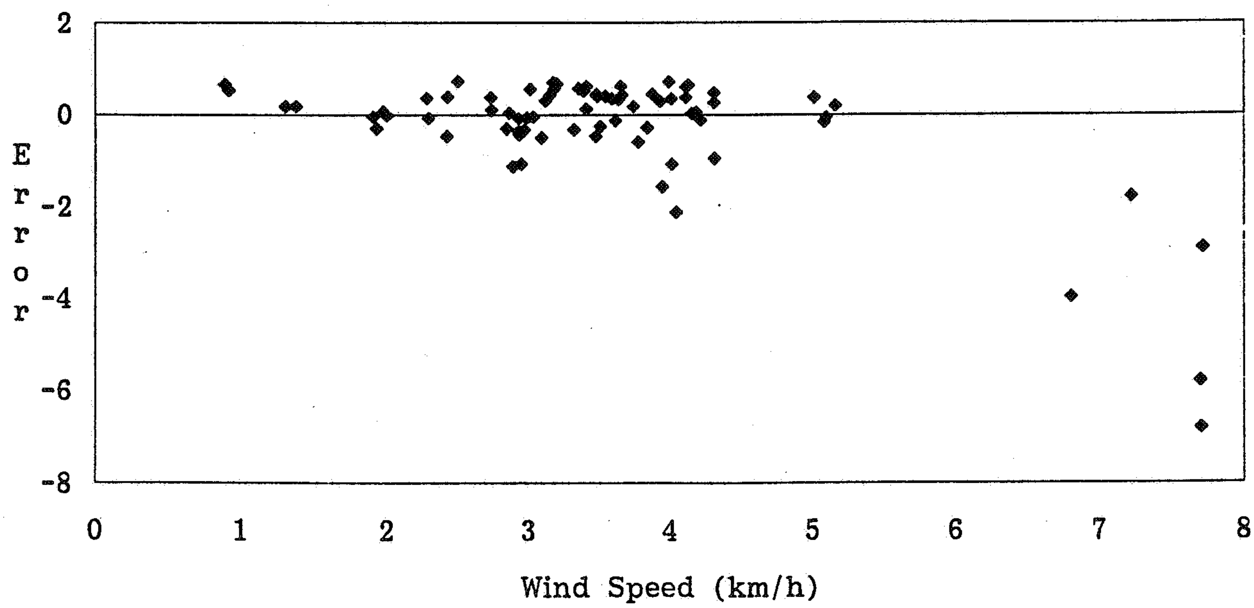
(6) Bowser Technical Inc., "Testing of Older Houses for Microbiological Pollutants", CMHC research report, Ottawa, Canada, December 1991.

(7) Palmiter, L., Bond, T., "Interaction of Mechanical Systems and Natural Infiltration", 12th AIVC Conference pp285-295, Ottawa, Canada, September 1991.

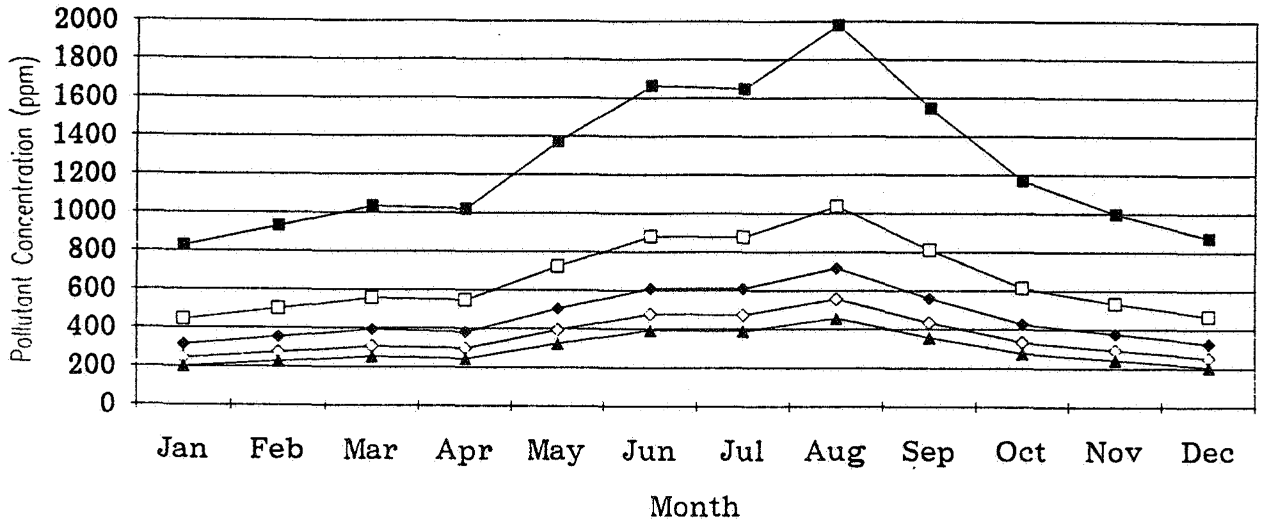
Graph #1 - PFT Measured vs. PFT Calculated



Graph #2 - Error vs. Wind Speed



Graph #3 - Mean Pollutant Concentrations (ppm) where Ventillation Rates Range from 50 to 250 Cubic Meters per hour with a Full-Time Occupancy of 3 People



Graph #4 - Number of Hours in October where pollutant concentrations exceeded 1000ppm