DISCUSSION

According to results the air exchange rate and the exhaust air flow in sanitary rooms in the houses with natural ventilation system were only about a half the values recommended by the Building Code. The recommendations were achieved in the reference house, which had a mechanical ventilation system. The CO_2-concentration, VOC-concentration and relative humidity are clearly correlated with the performance of the ventilation system and the human load. The air-exchange rate in the houses with natural ventilation (0.3 1/h) was sufficient to maintain the CO_2-concentration below the recommended value of 1500 ppm if only one person slept in the room and the door was open. The air exchange rate in the house equipped with the balanced ventilation system (0.4 1/h) was able to maintain reasonable CO_2-concentration in the bedroom with two persons. In the case when four persons slept in the bedroom, the system should have been run with a higher capacity. The results are in accordance with those reported e.g. in /1/ and /2/. The sample was limited because this kind of *in situ* measurements need huge resources. There is still a considerably large amount of houses, in which the families have bedrooms with high contaminant concentrations. We should pay special attention on the intake of fresh air, especially in bedrooms and on the operational conditions of ventilation systems.

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AIR EXCHANGE RATES IN RESIDENTIAL HOUSES

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ABSTRACT

The relationships between house characteristics and air exchange rate were examined. A representative sample of houses in the Boston Standard Metropolitan Statistical Area were selected. The sample was divided into terciles groups according to cumulative distribution of air exchange rate; the lower third and the upper third were used in the analysis. Air exchange rates were higher in dwelling units without an exterior storm door, with a small number of rooms (1-5), and in buildings with 5 or more units. These three characteristics may be related to the size and tightness of the dwelling unit.

INTRODUCTION

Air exchange rate (ACH) is a measure of ventilation. Ventilation rate is usually measured using tracer gases. Based on the mass balance assumption, air flow rate is determined as loss or removed air volume per unit period (1). ACH is obtained by dividing air flow rate by house volume. Reducting ventilation (i.e. lower ACH) will reduce energy consumption for residential space heating. Unfortunately, lower ventilation rates may lead to increased indoor air pollution. When considering energy consumption and the impact of indoor air pollution on human health, the mean air exchange rate over a period of weeks to months is relevant.

The objective of the Boston residential NO_2 characterization study was to quantify the fraction of total NO_2 exposure which may be attributable to unvented gas-fired appliances and other indoor sources (2). In this study, NO_2 concentrations and air exchange rates in over 500 households in Boston, Massachusetts were measured (3). In our previous paper, group means of ACH were compared to examined the effects of house characteristics on ACH (4). House characteristics related to ACH were building type, height of dwelling unit, energy conservation measures (such as double pane window and window caulking), and number of adult occupants (4). In this paper, the relationships between house characteristics and ACH are examined and a few attributable house characteristics to explain ACH distribution in residential houses are extracted, using categorical data.

MATERIAL & METHODS

Subject houses were selected to represent the total population of the Boston Standard Metropolitan Statistical Area (SMSA). A two-stage sampling scheme incorporating stratification by the kind of cooking fuel, was used for sampling and logistical efficiency. Detailed description of the sampling method has been reported elsewhere (3). A total of 973 eligible dwelling units were identified, with residents in 581 units agreeing to participate in the indoor NO_2 and ventilation monitoring. Finally, 501 houses were actually monitored in the winter of 1985.

Air flow rate was measured using by tracer gas method. Two types of tracer-gas, perfluoro-monomethyl-cyclohexane (PMCH) and perfluoro-dimethyl-cyclohexane (PDCH), were used (5). Air flow rate was calculated from the ratio of a tracer gas emission rate to an average concentration of PMCH and PDCH. Details of these measurements has been reported elsewhere (4). House characteristics were collected by a questionnaire that assessed house structure, energy conservation measures, heating systems, fuels, cooking, water heating fuels, ventilation, and occupancy.

Each house was placed into one of 3 groups according to cumulative distribution of ACH; the group ranges were 1-33.3, 33.4-66.6, and 66.7-100 percentile. Of these three groups, the lower third (1-33.3%) and the higher third (66.7-100%) were used in the analysis. The relationships between house characteristics and ACH were determined by cross-table analysis using Cramer's coefficient of association (V), and house characteristics affecting ACH were extracted. Cramer's V is one of the measure of association of the cross table. It is based upon χ^2 statistic. It ranges from 0 to 1 and when there is complete agreement between two variables, it can be 1 (6). In the first step, several variables with the large coefficient of association were selected. After the first step analysis, the cross-table analysis was applied to the each group classified by the variable selected at the first step to seek more house characteristics variables determining ACH. The procedure was repeated until the number of dwelling units in a specific category was too small to be analyzed. All variables selected by the cross-table analysis were considered to be key characteristics describing ACH. Multiple stepwise regression analysis was conducted to examine the strength of the key characteristics for the lower and the higher third ACH groups. Statistical analysis was conducted with SPSS/PC+ (7).

RESULTS

Out of 501 houses, tracer gas concentrations were monitored for two weeks of winter in 424 dwelling units. Two tracer gases, i.e. PMCH and PDCH, were successfully measured in 352 and 390 houses, respectively. The median ACH was 1.16 /hr. Divisions of ACH were based on 0.90 /hr at 33.3 percentile and 1.50 /hr at 66.7 percentile. The lower and the higher third ACH groups contained 89 and 79 houses.

The characteristics with higher than 0.4 of Cramer's V at the first step cross-table analysis were shown in Table 1. They were number of rooms in the unit (1-5, 6-19), house type (single unit, small multi-unit building (2-4), large multi-unit building (5+)), exterior storm door (No, Yes), number of exterior walls (1-3, 4), exterior building materials (wood-clapboard, brick-double brick, combination) and clothes dryer (No, Yes). They were used for the following cross-table analysis. In this paper, we described the results of the analysis by exterior storm door.

The result of the analysis by exterior storm door was shown in Figure 1. Seventy five percent of the dwellings without an exterior storm door were categorized into the higher ACH group and 74% of the dwellings with an exterior storm door were categorized into lower ACH group. These dwellings were enclosed by double line in Figure 1.

The results of the second step were followings. Number of rooms was selected in the dwellings without an exterior storm door (A in Figure 1). ACH in the dwellings with 1-5 rooms was higher and that with 6-19 rooms were lower. House type were selected in the dwellings with an exterior storm door (B in Figure 1). ACH in the single unit dwelling was lower. When the number of dwelling units in a building increased, ACH was higher.

Table 1. The result of first step cross-table analysis

Variable name	V
NUMBER OF ROOMS	0.512
HOUSE TYPE	0.504
EXTERIOR STORM DOOR	0.484
NUM. OF EXTERIOR WALLS	0.478
EXTERIOR BLD. MATERIALS	0.470
CLOTHES DRYER	0.438

The third step analysis about number of rooms, the category of 1-5 rooms was not further analyzed (C in Figure 1), since eighty six percent dwellings were included in the higher ACH. More detail classification was conducted on the category of 6-19 rooms. Gas water heater (No, Yes) was selected (D in Figure 1, V=0.800). All dwellings without gas water heater were classified in lower ACH and most dwellings with gas water heater were categorized in the higher ACH.

The third step analysis for the house type group was as follows. Rugs-carpeting (0%, 10-33%, 50-100%) was selected for the single unit dwellings (E in Figure 1, V=0.307). If the proportion of rugs-carpeting became higher, ACH decreased. Eighty percent of the dwellings with 50-100% rugs-carpeting were classified into lower ACH. As to the small multi-unit dwellings, air conditioning (No, Yes) was selected (F in Figure 1, V=0.404). ACH in the dwellings with air conditioning were lower. The further analysis was not conducted for the large multi-unit dwellings (G in Figure 1), since all (2 dwellings) were classified into the higher ACH groups. Finally, six variables were selected.

We conducted the same analysis for other variables in Table 1. Almost same variables as selected variables of the analysis by exterior storm door.

Then, multiple regression analysis was conducted using six variables (house type, number of rooms, exterior storm door, rugs-carpeting, gas water heater and air conditioning). Three of the six variables (house type, number of rooms and exterior storm door) were selected for ACH (Table 2). These three variables were selected at the first and second step analysis. Air exchange rates were higher in the dwelling units without an exterior storm door, dwelling units with a small number of rooms, and in large multi-unit buildings.

Table 2. The result of regression analysis

Variable name	Coefficient	t value	Sig. level
HOUSE TYPE	0.15200	2.159	0.0325*
NUMBER OF ROOMS	-0.23587	-2.466	0.0148*
EXTERIOR STORM DOOR	-0.19079	-2.077	0.0395*
RUGS-CARPETING	-0.03443	-0.491	0.6242
GAS WATER HEATER	0.07765	1.142	0.2555
AIR CONDITIONING	0.00356	0.051	0.9590
(CONSTANT)	1.68043	6.616	0.0000

DISCUSSION

In our study, three variables, exterior storm door, number of rooms and house type, were selected as major determinants for ACH. These variables were statistically significant in the regression analysis and it seemed they were reasonable to explain ACH in the residential houses.

Ventilation may be influenced by several physical factors, such as the indoor/outdoor temperature difference, wind velocity, wind direction, height of the building and openings of the building. It is considered that exterior storm door is related to openings of the building and house type to height of the building. These key characteristics may be related to the size and tightness of the dwelling unit.

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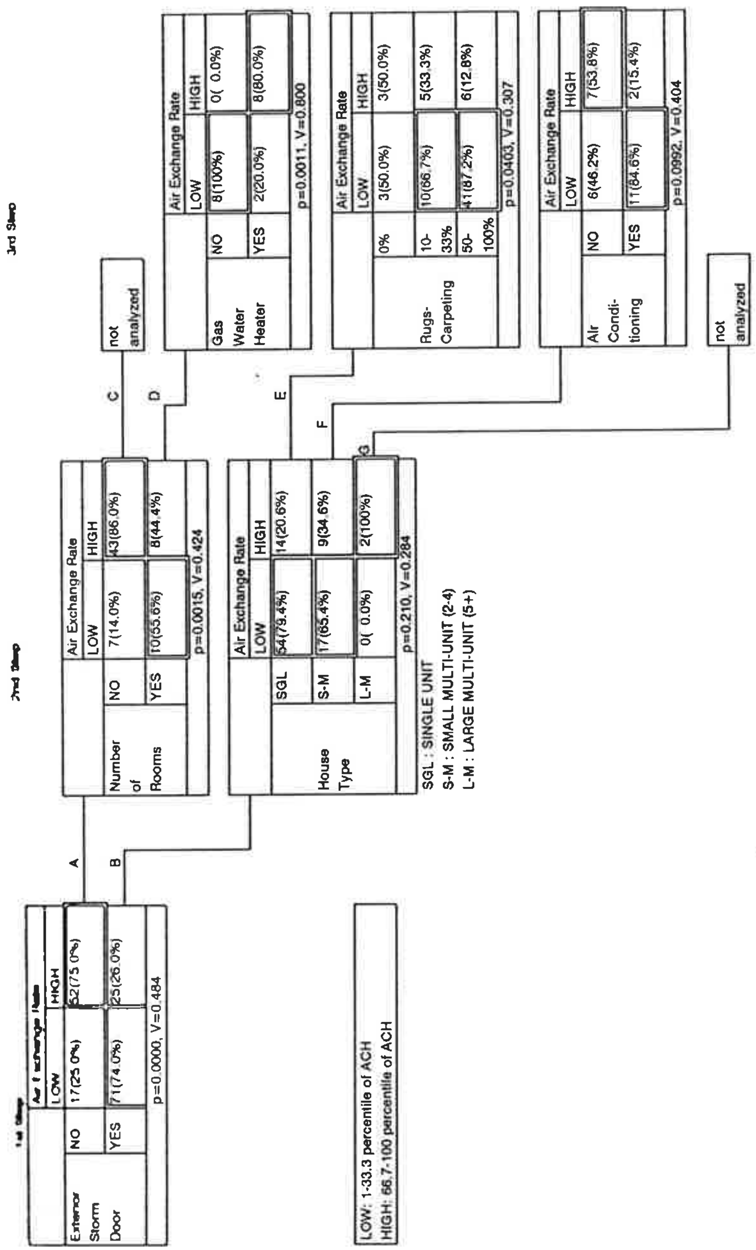

Figure 1. Classification of Air Exchange Rate by Exterior Storm Door