Title

PACIFIC NORTHWEST EXISTING HOME INDOOE AIR QUALITY SURVEY AND WEATHERIZATION SENSITIVITY STUDY

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Pacific Northwest Existing Home Indoor Air Quality Survey and Weatherization Sensitivity Study

Final Report

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PACIFIC NORTHWEST EXISTING HOME INDOOR AIR QUALITY SURVEY AND WEATHERIZATION SENSITIVITY STUDY

FINAL REPORT
TO THE
BONNEVILLE POWER ADMINISTRATION

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ABSTRACT

In a survey of 111 homes in the Pacific Northwest, indoor levels of formaldehyde (HCHO), nitrogen dioxide (NO_2), and water vapor were found to be significantly below levels of concern. Indoor radon concentrations were elevated in homes in the Spokane River Valley/Rathdrum Prairie region of eastern Washington and northern Idaho, which has highly permeable soil that encourages convective flow of radon-bearing soil gas. Forty-eight of these homes were studied to evaluate the effects of house weatherization on indoor air pollutant concentrations. Standard weatherization techniques reduced the specific leakage area (SLA), as measured by a blower door, in 40 homes by 12.5%, while the reduction in SLA due to wall insulation alone was not statistically significant. House doctoring in five homes resulted in an additional 26% decrease in SLA. Mean ventilation rates, measured with perfluorocarbon tracers (PFT) and uncorrected for environmental conditions, were 0.37 h^{-1} before weatherization and 0.39 h^{-1} after weatherization. These values were 20% lower than ventilation rates predicted using the LBL model. Good mixing of the indoor air causes uniform distribution of HCHO, NO_2, and H_2O vapor throughout interiors of the buildings. Respirable suspended particle (RSP) and NO_2 concentrations were low in those homes without tobacco smokers or without frequently used combustion appliances and were not dependent on high outdoor levels. Changes in concentrations of all pollutants and ventilation rates were generally small and essentially uncorrelated. Simplified models were developed to evaluate the impact of weatherization on normalized HCHO, H_2O vapor, and radon levels. The preliminary results demonstrated little conclusive change in indoor concentrations of these three pollutants due to weatherization, except in crawlspace homes where indoor radon levels were significantly reduced due to ventilation added to the crawlspace as part of the weatherization process. Other pollutants not modeled may respond differently to house weatherization. Additional study is necessary to evaluate other pollutants and to improve the predictive ability of the models.

EXECUTIVE SUMMARY

Participation by the Bonneville Power Administration in energy conservation activities, particularly weatherization of existing residences, raised questions regarding indoor air quality in these structures before and after weatherization. As a result of these concerns, this study was initiated to address the following objectives:

1) survey indoor pollutant concentrations in unweatherized Pacific Northwest housing,

2) study the effect of weatherization on house tightness, ventilation rates, and indoor pollutant levels.

The study consisted of a screening survey of indoor air quality in 116 unweatherized homes followed by staged weatherization in 40 of these 116 structures. An additional eight homes served as controls to the 40 receiving weatherization; monthly measurements of pollutant concentrations were made in these houses to track the impact of non-weatherization factors on pollutant concentrations.

The screening survey of 111 homes in and near Vancouver and Spokane, Washington, and Coeur d'Alene, Idaho, indicates that indoor concentrations of nitrogen dioxide (geometric mean of 5.1 ppb), formaldehyde (geometric mean of 37.2 ppb), and water vapor (arithmetic mean of 6.7 g/kg) were significantly below levels of concern. However, the survey led to the discovery of elevated indoor radon levels in homes in the Spokane River Valley/Rathdrum Prairie of Washington and northern Idaho. The geometric mean concentration (GM) for 43 homes in that area was 4.4 pCi/L, compared with the GM of other regional and national studies that range from 0.8 to 1.0 pCi/L. The high indoor radon levels found in the Valley/Prairie are due primarily to the convective flow of radon-bearing soil gas from a highly permeable, local soil.

The forty-eight homes from the screening survey that participated in the weatherization sensitivity phase of the study fairly well represented Pacific Northwest housing. The eight control homes remained unweatherized during the study. The other 40 homes underwent a variety of staged weatherization retrofits: wall insulation (14 homes), standard BPA weatherization (40 homes), and house doctoring (5 homes).

Spokane/Coeur d'Alene homes were more tightly sealed against air leakage, both before (geometric mean specific leakage area of 4.93 cm^2/m^2) and after (geometric mean of 4.11 cm^2/m^2) weatherization than the Vancouver area homes (geometric mean of 5.31 and 4.86 cm^2/m^2, respectively). Leakage area test results replicated quite well. BPA's standard weatherization program reduced the specific leakage area (SLA) of the 40 weatherized structures approximate 12.5%, while the reduction due to wall insulation was not statistically significant. House doctoring resulted in an additional reduction in leakage area of 26%.

Ventilation rates measured using passive sampling techniques and perfluorocarbon tracers (PFT) (uncorrected for different environmental conditions) had a geometric mean of 0.37 h^{-1} before weatherization, 0.39 h^{-1} after weatherization, and 0.30 h^{-1} after house doctoring. However, as observed in other studies and predicted from theoretical considerations, the PFT-measured ventilation rates averaged approximately 20% lower than ventilation rates calculated using a predictive model developed at LBL. This result creates a difficulty in recommending either the PFT technique or rates predicted by the LBL model for determination of individual house ventilation rates.

Because few unvented combustion appliances were used in these electrically-heated

homes, indoor nitrogen dioxide levels were very low (GM of 3.5 ppb). Indoor nitrogen dioxide levels remained low, even when outdoor levels were elevated. Respirable suspended particle concentrations (particles having diameters less than 3 μm) were usually higher in those homes where occupants smoked tobacco or where fireplaces or woodstoves were frequently used. In these homes, indoor levels could be quite high (up to 435 $\mu g/m^3$) and often exceeded the conservative National Ambient Air Quality Standard of 50 $\mu g/m^3$ for particles having diameters less than 10 μm (PM_{10}). Outdoor levels were elevated during periods of temperature inversion and often exceeded the same standard; however, there was poor correlation between indoor levels and high outdoor concentrations. Apparently, the penetration coefficient for transport of these particles through the building structure is small as suggested by other studies.

Since pollutants were monitored at multiple locations in each house, it could be determined that pollutants were uniformly distributed throughout the house interiors. This indicates that there is good mixing of the indoor air.

Changes in pollutant concentrations due to weatherization are difficult to interpret. Measured data from this study showed increases of 11% in water vapor concentration, 1% in formaldehyde concentration, and a reduction of 43% in radon concentration when the means of the pre- and post-weatherization samples are compared. However, these results represent measurements made during different environmental conditions. Therefore, the results must be corrected to standard conditions if meaningful comparisons are to be made. Water vapor concentrations were similar to those measured in the screening survey (arithmetic mean of 5.74 g/kg). Forty-two percent of the variation in indoor water vapor concentrations could be explained by variations in outdoor levels. Possibly because free formaldehyde has been depleted from the aged, UF-bonded, construction materials in these homes, indoor air formaldehyde showed little correlation to indoor water vapor levels. Indoor formaldehyde levels had a GM of 29.2 ppb. Indoor radon levels were higher in the Spokane/Coeur d'Alene homes (GM of 7.2 pCi/L), while Vancouver homes had a GM of 2.2 pCi/L.

Based on data from this study, comparisons of changes in indoor pollutant concentrations with changes in ventilation rates generally show little correlation between the two. Factors other than ventilation, including pollutant source strengths, occupant effects, and environmental conditions are probably more important in influencing indoor pollutant levels.

Simplified models were developed to evaluate the impact of weatherization on indoor air pollutants. The models were used to correct the measured radon, water vapor, and formaldehyde concentrations from before and after weatherization to standard conditions. With only one exception, these models demonstrate only very small changes in average indoor pollutant concentrations due to weatherization. The concentrations adjusted to standard conditions show an increase of 8% in post-weatherization water vapor concentrations relating to pre-weatherization conditions; a decrease of 2% in formaldehyde concentrations, and a decrease of 33% in radon concentrations. Only the changes in radon concentrations are statistically significant. Examining the radon data by substructure type, we show that only in crawlspace homes, where ventilation was added to crawlspaces during weatherization, were the indoor radon levels significantly reduced. Radon levels in homes with other substructure types may have also decreased due to weatherization, but the changes are not statistically significant.

Because sources were small (and concentrations low) for NO_2 and CO in these electrically heated homes, it was not possible to model changes in these pollutants. In other regions where unvented combustion appliances are prevalent, these combustion-related pollutants may exhibit larger increases after weatherization.

Although standard weatherization appears to have only a small effect on indoor air quality, these conclusions should be considered preliminary until monitoring techniques are improved; studies involving a larger number of homes and controlled laboratory experiments are conducted; and more sophisticated models are able to be used.

I. INTRODUCTION

A. BACKGROUND

In the public mind, indoor air quality problems have frequently been linked to energy conservation activities. Plausibility arguments support the contention that reducing ventilation in buildings, an important component of most conservation activities, causes a degradation of indoor air quality. However, only very little experimental evidence is available to support these arguments. Studies in North America of the effects of weatherization on indoor air quality have been reported by Young *et al.* (1981), Berk *et al.* (1981), Offermann *et al.* (1981), Nagda *et al.* (1985), Quackenboss *et al.* (1985) and Traynor *et al.* (1987).

Changes in building air leakage areas and in indoor pollutant concentrations were observed in all of the studies. But it was difficult to attribute these changes to the weatherization, which included house-tightening measures. One study (Nagda *et al.* 1985) developed house-specific models capable of predicting small changes in indoor air quality based on environmental parameters for two occupied Maryland houses that were identically constructed. But these results may have limited applicability to other house type and geographical regions.

The Bonneville Power Administration (BPA) was instructed in the Northwest Power Planning Act of 1980 to seek new energy supply from conservation before constructing additional power plants. One major conservation activity that was begun was a weatherization program in residences in the four-state area served by BPA: western Montana, Idaho, Washington, and Oregon. Because of the limited data on the impact of weatherization activities on indoor air quality, particularly for housing representative of that in the Pacific Northwest, BPA initiated the study reported here in order to investigate these questions and relationships.

B. OBJECTIVES

The study had three primary objectives:

1) survey the indoor pollutant concentrations in unweatherized Pacific Northwest housing,

2) measure the effect of standard weatherization procedures on house tightness and ventilation rates, and

3) relate changes in indoor pollutant levels to changes in house tightness caused by weatherization.

This is a final report to an earlier mid-term status report (Turk *et al.*, 1985). Data from that report is updated here and supplemented with a more comprehensive analysis of the housing survey and the effects of weatherization.

II. PROJECT DESIGN

A. PRELIMINARY DESIGN AND HOUSE SELECTION CRITERIA

To meet the objectives of the project, a study was designed that incorporated 1) a screening survey of approximately 120 homes to determine the distribution of pollutants in representative housing in the Pacific Northwest, and 2) a more intensive study of approximately 46 selected from the 120 homes to investigate the effects of staged weatherization and house tightening on indoor pollutant levels. The stages of weatherization were to include wall insulation, standard weatherization procedures,* and intensive house-tightening procedures known as house doctoring.

Two climatic zones (defined by BPA) were originally chosen for investigation. Climate zone no. 1 of western Washington and Oregon is characterized by mild, humid, coastal conditions and has less than 6000 degree-days (65° F basis). Climate zone no. 2, including much of eastern Washington and Oregon, is a continentally-influenced, great-basin, high plateau area with degree-days less than 7500, but greater than 6000. Climate zone no. 3 was not included in this study and is the mountainous area of Idaho and Montana having greater than 7500 degree-days.

In the original study design, the 120 homes were to be provided to LBL from the audit lists of utility companies participating in BPA's weatherization program. Sixty were to be from each of the two climatic regions. The Pacific Northwest Residential Energy Survey (PNRES) was to be used as a guide for selecting houses representative of the region, with the following criteria to be satisfied:

Construction Type - wood frame

Floor area, A. - 1000 $ft^2 < A < 2000$ ft^2

Age - 50% constructed pre-1970
50% constructed post-1970

Number of stories - 1 floor above grade

Substructure type - distribution of basements, crawlspace, and slab-on-grade

In addition, for the purposes of this study, all homes were to be owner-occupied, single-family dwellings with occupants interested in the research. The houses were to use electricity as their primary energy source for heat. The homes were to have been energy-audited but not weatherized, yet suitable for weatherization. They were to have a minimum of installed storm windows, caulking or weather-stripping, or extensive attic, crawlspace, or basement insulation. At least 30 homes from each region or climate zone were to have walls that were suitable for insulation.

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*At the time of the study, an energy audit of each house resulted in recommendations for standard weatherization practices including floor and ceiling insulation, caulking and weatherstripping, storm or thermal conversion windows, and crawlspace and attic ventilation. The program had not begun to recommend wall insulation as a standard measure.

A total of seven utilities were contacted requesting their interest in cooperating in this research project. Three were located in the western coastal area and four were located in eastern plains and mountain areas. Four of the seven utilities agreed to participate. For practical survey purposes, two specific locales (see Figure 1) and three of the four utilities were ultimately chosen. Vancouver, Washington, was selected from climate zone no. 1 and has average annual heating degree days totaling 4691. It is directly across the Columbia River from Portland, Oregon. Veradale, Washington, was chosen from climate zone no. 2 and is approximately 15 km east of Spokane (6882 average annual heating degree days). Because of the rather stringent house selection criteria and the fact that the Veradale district encompasses a small service area, sixty qualified homes were not available from that area. Therefore, the third utility was enlisted to provide additional homes. The utility is located approximately 40 km east of Veradale in Kootenai County, Idaho, and it includes Coeur d'Alene. It is also located in climate zone 2 and has climatological conditions similar to those of Veradale.

The utilities were also asked to provide a copy of the energy audit form, a floor plan, and their list of recommended weatherization measures for each house.

To provide a control group of unweatherized houses, BPA solicited employees through their newsletter in Vancouver, Spokane, and Idaho. Each control homeowner was to be compensated $25 monthly for participating in the study, since their houses would not be weatherized. Compensation for the other homeowners would be weatherization of their homes at no cost to them.

B. SCREENING SURVEY

A total of 116 houses was actually selected for the screening phase of the study. Of these, 71 were in the Vancouver area, and 45 in the Spokane/Coeur d'Alene area. Five houses dropped out of the screening study. Seventeen of the homes that belonged to BPA employees and one that belonged to a utility company employee were considered for use as control homes. Table 1 displays this information. These homes were monitored as described below and the data reviewed. A subset of approximately 46 homes was then to be selected for the follow-up weatherization sensitivity study.

Table 1. Screening Survey Participation
(Number of Homes)

	Vancouver, WA	Spokane, WA/ Coeur d'Alene, ID
Mailed passive monitor kits	71	29
Refused participation	3	2
Mailing Participation	68	27
Spot Radon-Only measurements	0	16
All Homes Participating	68	43 (Total - 111)

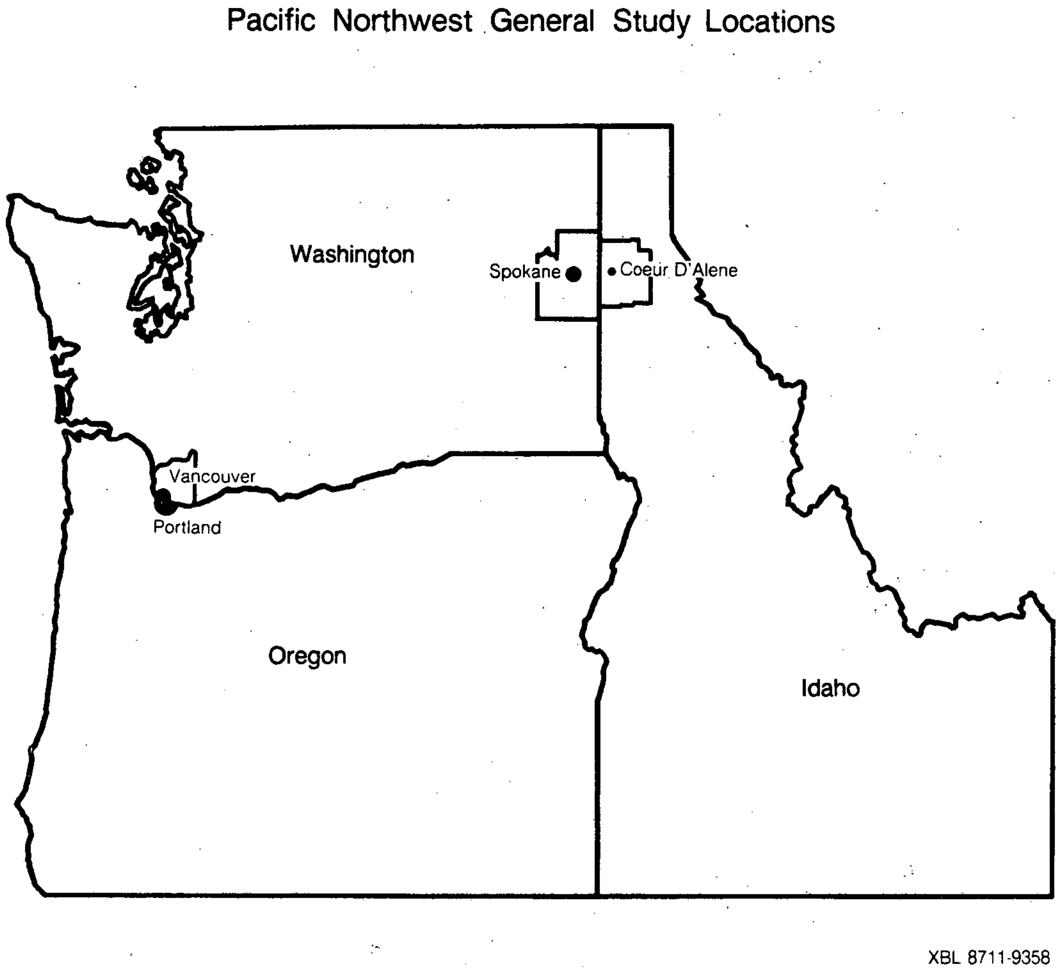

Figure 1 A map showing the regions where both phases of this project were conducted. Vancouver, WA, was chosen to represent the mild, coastal climate of climate zone 1, while Spokane, WA and neighboring Veradale were chosen for climate zone 2. Because an insufficient number of homes were available from the latter, Kootenai County, ID (containing Coeur d'Alene) was also included.

Details of housing characteristics for these structures are in Appendix A. The two areas differed in typical substructure type. Of the 45 Spokane/Coeur d'Alene homes, 35 had basements (81%). Twenty-four Vancouver area homes had basements (35%), while the majority had only crawlspaces (40/59%). The remaining houses had slab-on-grade or combinations of substructure types. Careful interrogation of the homeowners revealed that four houses in the Spokane/Coeur d'Alene group were heated with fuels other than electricity, but were kept in the study.

Monitoring Procedures.

After initial phone and letter contact, residents of 100 homes were sent air sampling kits containing passive monitors for four pollutants: radon, formaldehyde (HCHO), nitrogen dioxide (NO_2) and water vapor (H_2O) during the months of October through December, 1984. See Figure 2. Replicate samplers for HCHO and radon were included to improve the precision of these measurements. The kits also included instructions for deployment and retrieval of the monitors, a foam rack to hold the monitors during sampling, labels for recording dates, times, and location of samplers, a brief questionnaire, a simple floor plan diagram of the homes from the energy audit, and a postage-paid box and envelope for return shipment of the kit.

Approximately one week after the kits were mailed, the participants were again contacted by phone and instructed to deploy the samplers. At this time, assistance was given to complete the questionnaire and any questions from the participants were answered. The air samplers were deployed (open end up) in one location within each house, usually in the living room. Participants were instructed to place the samplers near the center of the room, away from outside walls, windows, combustion appliances, etc. Participants were also asked to record the location of the samplers on the test kit labels and on the floor plan diagram. Outdoor measurements were not made.

Seven days after deployment, another call was made instructing the participants to cap and return the HCHO, NO_2, and H_2O monitors in the postage-paid return mailer, along with the questionnaire and diagram. After an additional 14 to 28 days, the participants were again contacted and asked to return the radon detectors in a separate postage-paid return mailer.

Early results from Veradale indicated that many homes had elevated radon levels. To augment the number of homes studied, an additional 16 homes in the Spokane/Coeur d'Alene area were selected from utility company audit logs and screened for radon only. A technician visited each of the homes and sampled air on the first occupied floor above grade using a continuous radon monitor (CRM) for approximately 30 minutes to determine the short-term indoor radon concentrations. These homes were then also considered for selection into phase 2 based on their house characteristics and radon levels.

Instrumentation.

The preparation, assembly, and analysis of the HCHO, NO_2, and H_2O passive monitors used in the kit were performed in the LBL passive sampler laboratory using modified versions of established methods (Geisling *et al.* 1982; Palmes *et al.* 1976; Girman *et al.* 1986, respectively). These diffusion-controlled devices collect pollutants on material at the end of an open tube and provide time-weighted average concentrations during the exposed period. Experiments were conducted to determine whether the passive monitors were sensitive to orientation during sampling. No differences were observed between those samplers exposed open end up or open end down. Minimum detection limits for these samplers were HCHO - 11 ppb, H_2O - 0.5 g/kg, NO_2 - 2 ppb. See Appendix B for details. The radon Track-Etch® type SF detectors were supplied and analyzed by the manufacturer, Terradex Inc. Less than 3% of all samplers were lost, damaged, or otherwise rendered useless during shipping and exposure. The cost of

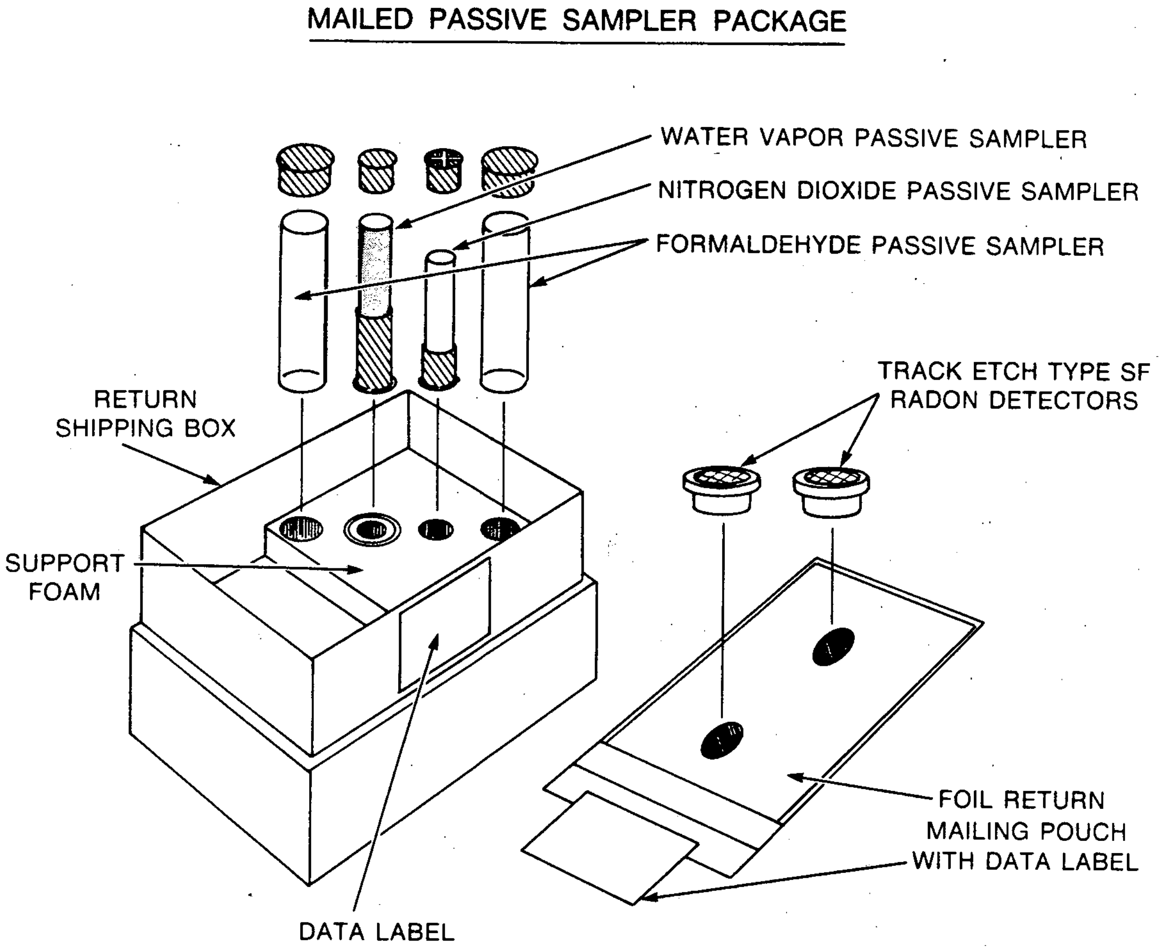

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Figure 2 These kits containing passive air monitors for radon, HCHO, H_2O, and NO_2 were mailed to 100 residences as part of the screening phase of the project. Enclosed instructions, plus telephone assistance, enabled the homeowners to deploy the monitors and return them to LBL in the postage-paid mailers after exposure was completed. Monitors were placed with the open end up.

the air sampling kit, including shipping, phone contacts, and analysis, was approximately $150/kit.

C. WEATHERIZATION SENSITIVITY

The purpose of this phase of the study was to determine whether changes in indoor pollutant concentrations could be related to changes in house air leakage area or ventilation rates resulting from various weatherization procedures. To make that determination, a study with a sufficient number of homes having measureable pollutant concentrations was necessary.

House Selection.

The sample size for this phase of the study was chosen to detect a change of 20% in the mean pollutant concentration in the houses with 90% confidence, subject to the constraints of the budget available for the project. This was done using a Monte Carlo simulation routine on the LBL central computer system. Pollutant concentration distributions were assumed based upon the then-known information about radon, formaldehyde, and NO_2 concentrations in houses. A sample of measurements was simulated for a group of houses using the assumed concentration distributions. The distributions were then translated upwards 10, 20, and 30% to simulate the effects of weatherization. These new simulated measurement distributions were generated by the computer. The simulated measurement results for the post-weatherization condition were then compared to the sample's base line values. The procedure was repeated 100 times. The results showed that a sample size of forty houses would resolve a 20% difference in sample means with 90% confidence. This was consistent with the financial constraints on the study and, therefore, formed the basis for the sample size used.

Selection of houses from the screening survey into the more intensive weatherization sensitivity study involved two basic criteria:

1) Homes were to have a measurable pollutant level at least five times greater than the minimum detection limit of the pollutant sampling device. These concentration limits were selected to allow the indoor concentrations to increase or decrease as a result of weatherization, yet still be detectable following that change. The majority of the homes in the Vancouver area were selected into the project based on their formaldehyde concentrations. In the Spokane/Coeur d'Alene area, they were selected primarily for their indoor radon concentrations. However, some of the Spokane/Coeur d'Alene homes also met the selection criteria for formaldehyde, while some Vancouver homes met the radon criteria.

No homes were selected into this phase of the study based on elevated NO_2 levels, since indoor concentrations of this pollutant were quite low. This was a result of most homes having electric heating and cooking appliances.

2) Houses were to have representative construction characteristics. Houses selected into this phase of the study were to fit the distributed house characteristics of the PNRES (Table 2). The group of 1868 homes from the PNRES were all single-family electrically-heated buildings. They were selected from the much larger group of Pacific Northwest houses that were surveyed by the PNRES. Table 2 also summarizes important house characteristics by region for houses studied in phase 2 and compares them to the PNRES distribution. Selection of houses into the weatherization phase began in November 1984, after the results of the screening survey were received. Selection continued into February 1985, as additional homes were screened and reviewed and included in the project. Of the substructure types, basements were generally over-represented as compared to the PNRES. Other house characteristics match quite closely to those of PNRES.

The sample was further restricted according to the additional house and occupant stratification

TABLE 2. BUILDING CHARACTERISTICS AND SAMPLE REPRESENTATIVENESS: COMPARING THE PNRES AND PHASE 2 WEATHERIZATION SENSITIVITY HOMES

	Pacific Northwest Residential Energy Survey (PNRES)				Weatherization Sensitivity Study											
	Climate Zone				Spokane/Coeur d'Alene				Vancouver				All			
	2 & 3		1		Study		Control		Study		Control		Study		Control	
CLASSIFICATION	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
No. of Stories: 1/2	24	2	4	1	0	0	0	0	0	0	0	0	0	0	0	0
One	919	77	491	73	10	50	1	20	15	75	2	67	25	63	3	38
One-1/2	ND		ND		4	20	2	40	1	5	0	0	5	13	2	25
Two	197	17	141	21	6	30	2	40	4	20	1	33	10	25	3	38
Three	20	2	7	1	0	0	0	0	0	0	0	0	0	0	0	0
Floor Area: <1000ft2	200	17	135	20	5	25	0	0	4	20	1	33	9	23	1	13
1000-2000 ft2	596	50	386	57	9	45	2	40	13	33	2	67	22	55	4	50
>2000 ft2	382	32	151	23	6	30	3	60	3	15	0	0	9	23	3	38
Construction Year: <1950	365	31	153	23	8	40	2	40	5	25	1	33	13	33	3	38
1950-1974	391	33	290	43	8	40	2	40	10	50	1	33	18	45	3	38
>1974	398	33	175	26	4	20	1	20	5	25	1	33	9	23	2	25
Substructure Type: Basement	599	50	137	20	18	90	5	100	7	35	1	33	23	63	6	75
Crawlspace	640	49	511	76	10	50	3	60	15	75	2	67	25	63	5	63
Slab	176	15	132	20	1	5	1	20	6	30	0	0	7	18	1	13
Wood Burning Appliance: Wood Stove	155	13	62	9	5	25	5	100	2	10	2	67	7	18	7	88
Fireplace	242	20	200	30	10	50	4	80	17	85	2	67	27	68	6	75
Other	9	0.01	0	0	2	10	0	0	0	0	0	0	2	1	0	0
Other Combustion Fuels:	38	3	18	3	2	10	2	40	2	10	0	0	4	10	2	25
Homes with Smokers:	ND		ND		7	35	2	40	6	30	0	0	13	33	2	25
Total Number of Buildings:	1191		677		20		5		20		3		40		8	

Note: 1. All homes are single-family with electric as primary heat
2. Spokane/Coeur d'Alene = climate zone 2& 3; Vancouver = climate zone 1
ND = Data not collected by this category-type

criteria of Table 3. This table shows the stratified study design specifications to evaluate the climatic and construction differences. The construction differences included age because it could affect formaldehyde emission rates, and substructure type since it is likely to affect radon entry and accumulation in these buildings. The design also included a category for homes with combustion devices and the presence of tobacco smoking since these will affect respirable suspended particle concentrations. The design matrix called for a certain number of homes in each bin and is identified in Table 3 as the "design" column. While the number of homes in each bin is small, it was hoped that moderate differences in air quality parameters between the clusters would be detectable. The actual number of homes is somewhat different from the design. This resulted from limitations in the sample of available homes (e.g., no home had urea formaldehyde foam insulation, UFFI, in the walls) and the necessity that the homes have measurable pollutant levels. The competing requirements of having a representative sample, yet having a sufficient number of homes in each bin, were met fairly well.

Both in Vancouver and Spokane/Coeur d'Alene, more older homes were included in the study than was required by the design. Once again, the limited number of homes available restricted our ability to fill this stratification cluster. Appendix C compiles the structural characteristics of houses participating in this phase of the study.

TABLE 3. SAMPLE STRATIFICATION
HOUSES REQUIRING WEATHERIZATION
DESIGN VS. ACTUAL

Stratification Criteria	Vancouver (No. of Houses)		Spokane/Coeur d'Alene	
	Design	Actual	Design	Actual
Formaldehyde: Age - pre 1974	10	15(2)	10	16(4)
post 1974	10	5(1)	10	4(1)
UFFI# - Yes	10	0	10	0
No	10	20(3)	10	20(5)
Radon: Substructure - basement	7	3(1)	7	10(2)
crawlspce	7	11(2)	7	2
basement w/crawl	-	4	-	8(3)
slab-on-grade	6	6	6	1(1)
Combustion Sources: smokers - yes	10	6	10	7(2)
no	10	14(3)	10	13(3)
appliances* - yes	10	7(3)	10	11(5)
no	10	13	10	9
Requiring BPA Weatherization	20	20	20	20
Requiring Wall Insulation	10	9	10	8(1)
Requiring House Doctor Weatherization	5	3	5	2

( ) indicates number of control homes in that cluster

Urea formaldehyde foam insulation

*includes predominantly woodstoves and fireplaces, but also includes kerosene heater, a propane stove, and an auxiliary oil furnace

The study design originally called for 20 homes to be weatherized and three control homes in each of the two regions. However, one Spokane control home dropped from the project after participating in one measurement period. As the area of the study was expanded to include Kootenai County, Idaho, two additional control homes had to be added in that area. Therefore, the total number of control homes in the Spokane/Coeur d'Alene area was five, and the total number of homes involved in the weatherization sensitivity phase of the project was 48. It should also be noted that one Veradale home was selected as a control (ESP010C), because of our concern that weatherization could elevate the pre-existing high indoor radon concentration (27.2 pCi/L).

Homeowners were contacted by phone and mail regarding their selection into the project, and were asked to sign temporary use permits allowing researchers to conduct the necessary measurements in the houses. They were also asked to sign a house-tightening informed-consent agreement stating that weatherization may cause houses to be tightened and indoor pollutant levels to go up. If pollutant levels rose in response to the project-sponsored weatherization, the homes were eligible for a follow-up mitigation and pollutant control project to reduce pollutant concentrations to pre-weatherization levels.

Measurement Protocol.

The goal of the study was to cause and measure changes in house air tightness (and indoor pollutant concentrations) as a result of specific weatherization techniques. It was not to achieve a similar specified air leakage area or ventilation rate in all of the weatherized houses. Therefore, weatherization was performed and evaluated in three stages. Figure 3 is a block diagram of the staging protocol.

First, wall insulation of blown cellulose or blown or batt mineral fiber was installed in 14 homes from the two regions. Secondly, standard BPA-recommended weatherization was performed in all 40 study homes. Utility company representatives had previously visited the houses and performed an energy audit. From this audit, various weatherization measures were recommended on the basis of standards developed by BPA. The recommended work was performed by contractors and included caulking, weatherstripping, attic and crawlspace insulation, storm windows, and ventilation of crawlspaces and attics. Obviously, the amount of weatherization performed at each house was different and depended upon the weatherization already present and the house construction. A complete itemization of the weatherization performed on each house is listed in Appendix D. Finally, five homes were "house doctored," a process of intensive house-tightening weatherization that incorporates a blower door to pressurize (or depressurize) the building to identify air leakage paths and includes sealing the floors and attic bypasses. The contractors performing the work were required to show a 30% reduction in the effective leakage area (ELA) or predicted natural air infiltration rates by using blower-door-generated leakage areas. Therefore, four homes received all three stages of weatherization (wall insulation, standard weatherization, house doctoring), 10 homes received wall insulation and standard weatherization only, one home received standard weatherization and house doctoring, and 25 homes received standard weatherization only (Table 4).

Typically, BPA paid utility companies participating in their weatherization program 80% of the cost of the retrofits on each house. Homeowners were responsible for the remainder. As compensation for participating in this study, LBL assumed financial responsibility for the howeowner's portion. LBL also covered the cost for all of the house doctoring work.

Each stage of weatherization was preceded (baseline) and followed by a seven- to ten-day period of intensive monitoring. Because of scheduling difficulties with the limited amount of monitoring equipment and with the weatherization contractors, weatherization did not always immediately follow measurement periods, and measurement periods did not always immediately

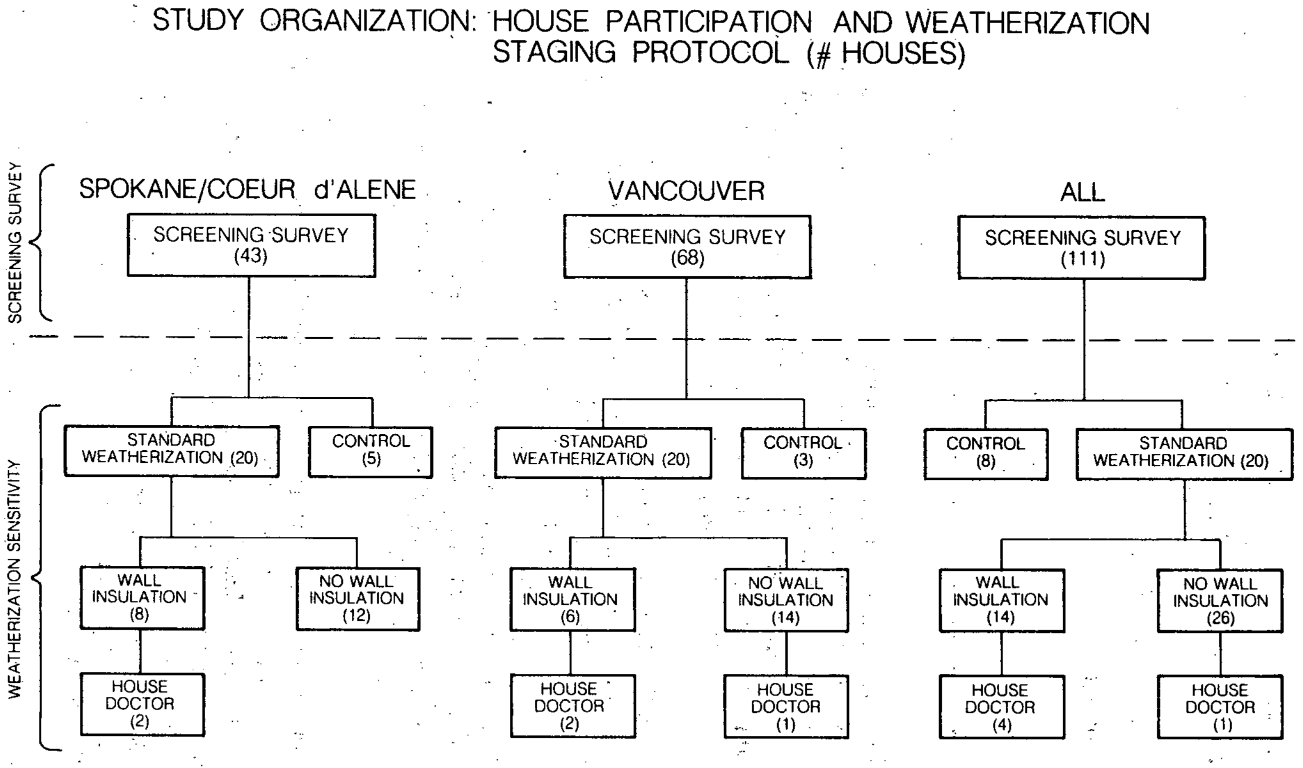

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Figure 3 Block diagram showing a simplified organization of the house selection process and protocol for staging weatherization.

Table 4. Number of Houses Participating in Weatherization Stages

Stages of Weatherization Performed	No. Houses
Wall insulation + std. weatherization + house doctoring	4
Wall insulation + std. weatherization	10
Std. weatherization + house doctoring	1
Std. weatherization only	25

follow weatherization. Therefore, the measurement periods pre- and post-weatherization are not always under the same environmental conditions. Since all houses could not be monitored at the same time because of the equipment limitations, instrumentation was moved from houseto house as weatherization was completed. It was hoped that subsequent data analysis and modeling could normalize measurement data to standard conditions so that pre- and post-weatherization pollutant concentrations could be compared.

Control homes were typically monitored on a monthly basis in Vancouver. In the Spokane/Coeur d'Alene area, control homes were monitored on a more irregular basis because of difficulties with the subcontracted technical service and because one home withdrew from participation. Local subcontractors provided technicians who installed and serviced instruments and conducted measurements. They also coordinated with various weatherization contractors on the installation date for the weatherization. All weatherization except for the house doctoring work was inspected by BPA personnel. LBL staff supervised all technical operations in the field and conducted a two-day training session for the technicians.

Instrumentation.

Many more instruments were installed and measurements made during the weatherization phase of the project than during the screening survey. Table 5 summarizes the primary measurement devices and techniques that were used. Passive samplers, identical to those used in the screening survey, were used to monitor NO_2, HCHO, and H_2O at three-to-five indoor locations in occupied zones and at one outdoor location at each house. For this phase, the samplers were suspended in an aluminum rack at each of the deployment locations (Figure 4) for approximately seven to ten days. As in the screening survey, these samplers were prepared and analyzed in a special LBL laboratory facility.

Time-weighted average samples of respirable suspended particles (RSP) were collected on 37 mm diameter 0.8μm pore size Teflon filters, at one indoor and one outdoor location at each house. The sample was drawn at 1.7 LPM through a 10-mm nylon cyclone with a 3μm cutpoint by a flow-controlled pump system. Sampling was concurrent with the passive monitors. These filters were analyzed gravimetrically by Clayton Environmental (formerly McKesson Environmental Services). Selected samples were analyzed for seven polynuclear

Table 5. Instrumentation and Analytical Techniques

Pollutant	Sampling Device	Analytical Techniques
HCHO	LBL Passive Sampler	Spectrophotometric
H_2O	LBL Passive Sampler	Gravimetric
Rn	Terradex Corp. Type SF Track Etch Sampler	Count number of tracks on alpha-sensitive film, performed by Terradex Corp.
	Continuous Radon Monitor (CRM) transmitting to data logger	Continuous flow alpha scintillation cell
NO_2	Palmes' Passive Sampler	Spectrophotometric
RSP	Flow-Controlled Filtration Device with 3 μm cut-point cyclone	Gravimetric
PAH's	Selected RSP samples	HPLC, performed by Clayton Environmental
CO	LBL Constant-Flow Gas Collection Bag	General Electric Electrochemical Analyzer
Tracer	Ventilation Measurement Device	Analytical Technique
Multiple Perfluorocarbons	Source: Permeation Tubes with Colocated Max-Min Thermometers Sampler: Passive Adsorption Tubes	Brookhaven National Lab. AIM System. Thermal Desorption and ECD/GC Analysis
	Continuous Monitoring	
Parameters	Device	Data Acquisition
Indoor, outdoor temperature	AD-590 IC temperature sensor	LBL 17-channel with EPROM data storage
Windspeed and direction	On-site meteorological tower	LBL 17-channel with EPROM data storage
	Other	
Building air leakage area	Depressurization blower door	

aromatic hydrocarbons (PAH) listed on Table 6. Persistent pump problems were experienced with the RSP flow-control units used throughout the project. Consequently, processing of the PAH data has been delayed and the preliminary results are not reported here. Carbon monoxide (CO) samples were collected in Tedlar bags using constant flow, peristaltic pumps. Analysis was by a portable General Electric electro-chemical analyzer. The minimum detection limit of this analyzer is approximately 2 ppm, and the vast majority of CO data values were at or below this detection limit.

For each house, temperature sensors were located at two to six indoor locations and at one outdoor location on a weather tower that also had wind direction and speed sensors. All of these data were monitored continuously and recorded on a data acquisition system. Radon was

Table 6. Characteristics of Selected Polycyclic Aromatic Hydrocarbons

PAH	Chemical Formula	Melting Point (°C)	Sublimation Point (°C)
Chrysene	$C_{18}H_{12}$	254	190
Benzo[b]flouranthene	$C_{20}H_{12}$	168	ND
Benzo[k]flouranthene	$C_{20}H_{12}$	217	ND
Benzo[a]phrene	$C_{20}H_{12}$	178	ND
Dibenz[a,h]anthracene	$C_{22}H_{14}$	262	ND
Benzo[g,h,i]perylene	$C_{22}H_{12}$	279	ND
Indeno[1,2,3-cd]pyrene	$C_{22}H_{12}$	ND	ND

ND = No data

also measured continuously at one indoor location on the first occupied floor above grade with a continuous radon monitor (CRM) designed and built at LBL using a flow-through alpha-scintillation cell. Amplified pulse signals corresponding to detected alpha decays were sent to the data acquisition system. Data from all active sensors were recorded for 30-minute intervals on an LBL-designed and -built data acquisition system with an EPROM data storage module. Considerable problems were experienced with this data acquisition system and forced abortion of many tests early in the project. Some data were lost, but most tests were rerun and data were recovered for equivalent periods. Upon completion of a monitoring period, the EPROM was removed and the data were downloaded to the LBL main-frame computer system.

Time-averaged ventilation rates were measured with a passive constant-emission, passive collection system using perfluorocarbon tracer (PFT) gases (Dietz and Cote, 1982). Three distinct tracer gases were used to label separate building zones. Since the tracer source permeation rates were temperature-dependent, a maximum/minimum thermometer was colocated with the tracer source. Tracer sources were placed one for approximately every 45 m^2 of floor space away from doors, windows, and heat sources and remained in place during the course of the study. Tracer samplers were deployed with the pollutant samplers (Figure 4).

Blower door pressurization tests were made during each monitoring period to quantify changes in air leakage area due to weatherization. These data were then used in a model developed by Sherman and Grimsrud (1980) to predict the ventilation rate for that particular period. The blower doors were calibrated at an LBL test facility before and after the study.

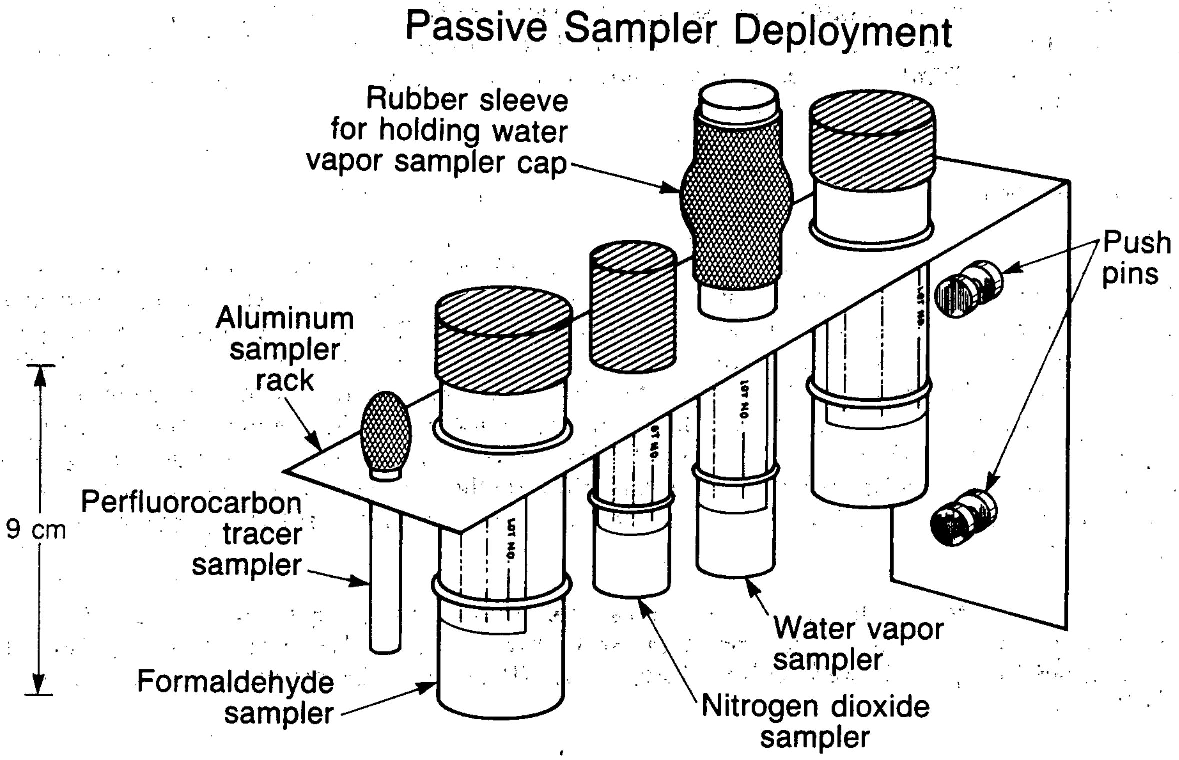

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Figure 4 Drawing of the deployment method for passive samplers for HCHO, H_2O, and NO_2, and for the PFT ventilation measurement system. The samples were suspended in aluminum racks which were placed at three to five indoor measurement locations and one outdoor location (without PFT sampler) at each house in the weatherization phase of the project. Technicians exposed the samplers for seven to ten days. Samplers were identical to those in Figure 2.

In addition to the intensive monitoring periods that used data loggers recording data from continuously operating monitoring equipment, seven-day passive monitoring of pollutants (H_2O, HCHO, NO_2) and ventilation was conducted once or twice at some of the houses. This monitoring increased the data available for studying the relationships of these pollutants to changes in ventilation. Continuous data were not collected during these periods. Data on environmental conditions, pollutant concentrations, ventilation rates, and air leakage area for all test periods are summarized in Appendix E.

During the first visit made to each house, the technicians recorded various data pertaining to the house construction characteristics. On subsequent visits, they would deploy passive monitors, note the operation of equipment, change filters in the RSP device and CRM, record maximum/minimum temperatures, and exchange the EPROM data modules.

Concurrent with the measurement periods, the occupants were asked to keep a diary of daily activities that might affect the indoor air quality in their home. This diary requested such information as: number of occupants, cigarette smokers, and other activities such as fireplace operation and exhaust fan operation.

D. PILOT STUDY.

A pilot study was conducted before the large study began to evaluate screening techniques and instrumentation. Letters were sent to 51 Oakland, California, homeowners, soliciting their participation in a week-long indoor air quality study. These homeowners were on a city planning mailing list for energy conservation materials. To evaluate the inducement of a $25 compensation, 24 homeowners were sent letters indicating that they would be compensated for the participation. The other homeowners were not notified of the compensation. Thirty-seven percent (19) of all homeowners responded. Six homeowners had moved. Forty-seven percent of the respondents had received a letter mentioning the $25 compensation, while 53% did not know they would be compensated. Monetary compensation did not appear to motivate participation.

Seven homes were selected from the 19 respondents to undergo monitoring for seven days as an evaluation of instrumentation and procedures. Data from these seven homes are summarized in Appendix F and include NO_2, HCHO, H_2O, RSP concentrations, and predicted ventilation rates.

III. MEASUREMENT RESULTS

A. SCREENING SURVEY

Test results from the phase 1 screening survey are displayed in Figures 5 and 8 to 13, Tables 7 to 10, and are detailed in Appendix A.

Radon.

A wide range of indoor (living space) radon concentrations was measured in the 111 homes tested in phase 1 (Figure 5). The distribution of concentrations can be compared to that observed by Nero *et al.* (1986) in a review of 552 U.S. homes (Figure 6) and Thor (1984) in a regionwide survey of 268 BPA employee homes (Figure 7). While the mean concentration from the present survey is higher than these other studies, the form of the distribution is similar. The higher mean is due to the inclusion of 43 Spokane/Coeur d'Alene homes in the sample and becuase data were collected only during the heating season. It is important to keep in mind that, although useful as a simple high/low radon detection technique, the 30-minute CRM measurement conducted in 16 of these 43 homes may not be a representative measure of longer-term average radon concentrations. As an improvement, average radon concentrations measured with the CRMs during the 7- to 10-day baseline weatherization period have been substituted for those 13 homes that subsequently participated in the weatherization sensitivity phase. Thirty of the homes surveyed in phase 1 had two- to four-week average concentrations at or above the BPA 5.0 pCi/L action level with only four of these homes located in the Vancouver area. Another five homes had concentrations between 4 and 5 pCi/L, where 4.0 pCi/L is the recommended EPA guideline.

A separate distribution for the Spokane/Coeur d'Alene homes in phase 1 was generated (Figure 8) and reveals the existence of the many high radon homes in the area. Further study of radon in these homes has shown that the elevated levels are primarily due to the gravelly, highly permeable soil found in the Spokane River Valley and Rathdrum Prairie. A large part of Kootenai county and most of Veradale overlay this soil. More discussion of these data is found in Turk *et al.* (1987a). Of the 43 Spokane/Coeur d'Alene homes, 67% (29) were above the current EPA guideline.

The regional difference is also apparent in Table 7 where Spokane/Veradale area homes had a geometric mean radon concentration of 5.5 pCi/L (GSD of 2.6) and the Vancouver homes a geometric mean of 1.2 pCi/L (GSD of 2.2). The sixteen 30-minute CRM measurements from Kootenai county (Coeur d'Alene) homes were not included in this comparison. If the passive monitor data are aggregated instead by substructure type (Table 8), we see that homes with only basements tend to be slightly higher in indoor concentrations (geometric mean of 2.7 pCi/L) and those with only crawlspaces have slightly lower levels (geometric mean of 1.4 pCi/L). Homes with other substructure types generally had levels between those two extremes, except for that category having a basement or crawlspace with a slab (1.3 pCi/L). A dependence on substructure type could be related to the high incidence of basement homes in the Spokane/Veradale area -- 20 of the 34 basement-only homes were from that area. It is also plausible that basements provide more numerous entry paths and direct coupling between the house and soil. Most of the homes with only a crawlspace substructure were from the Vancouver area (29 of 31). Another reason for crawlspace homes having a lower mean radon level is that crawlspaces often have more outside air ventilation than basements, thus decoupling the house from the soil and removing radon from the crawlspace before it can enter the house.

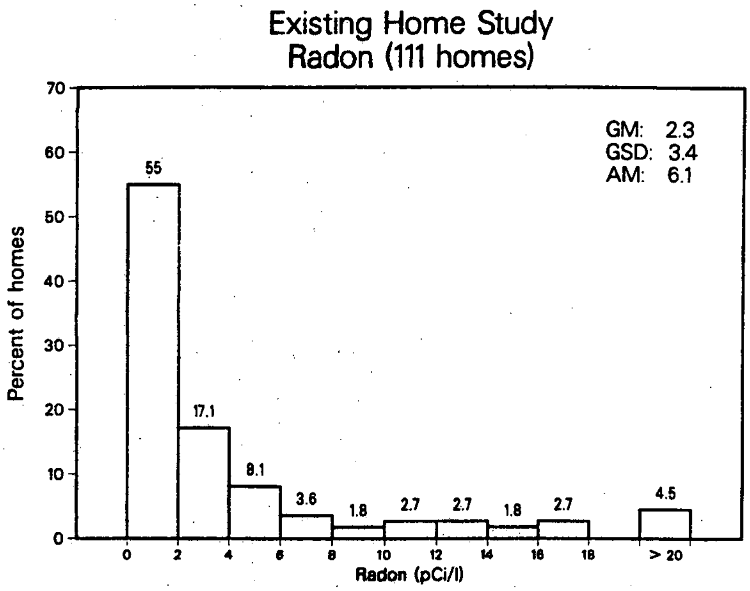

Figure 5 Histogram of indoor radon concentrations measured at 111 homes during the screening phase. Data from 13 of the Spokane/Coeur d'Alene homes are from the 7- to 10-day weatherization period continuous radon measurement. Data for three other homes from this same area are based on 30-minute CRM monitoring. All other data are from a 21- to 35-day alpha track detector measurement during October through December.

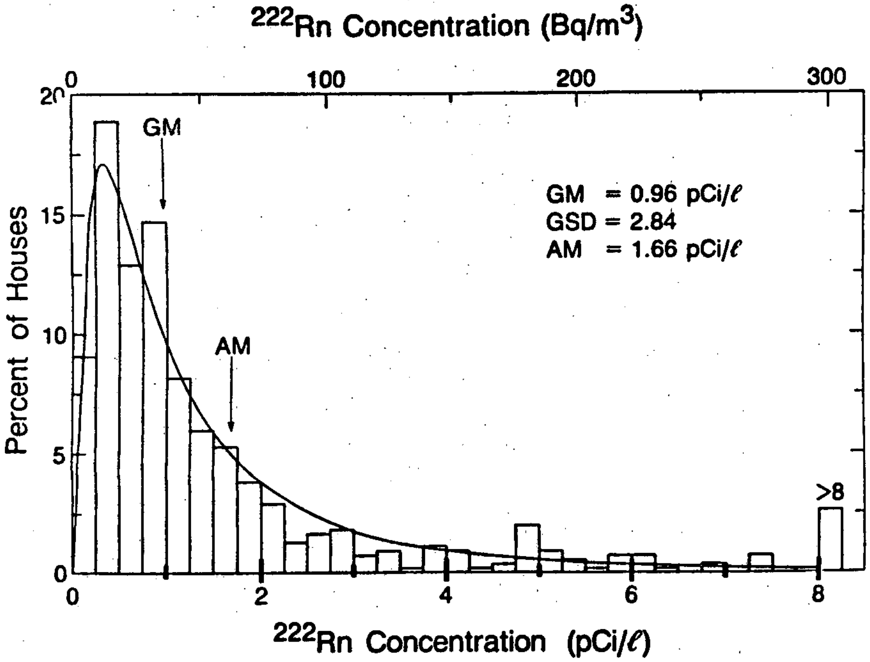

Figure 6 Radon distribution for 552 U.S. Homes as summarized by Nero et al., 1986. Data are distributed lognormally with a geometric mean of 0.96 pCi/L.

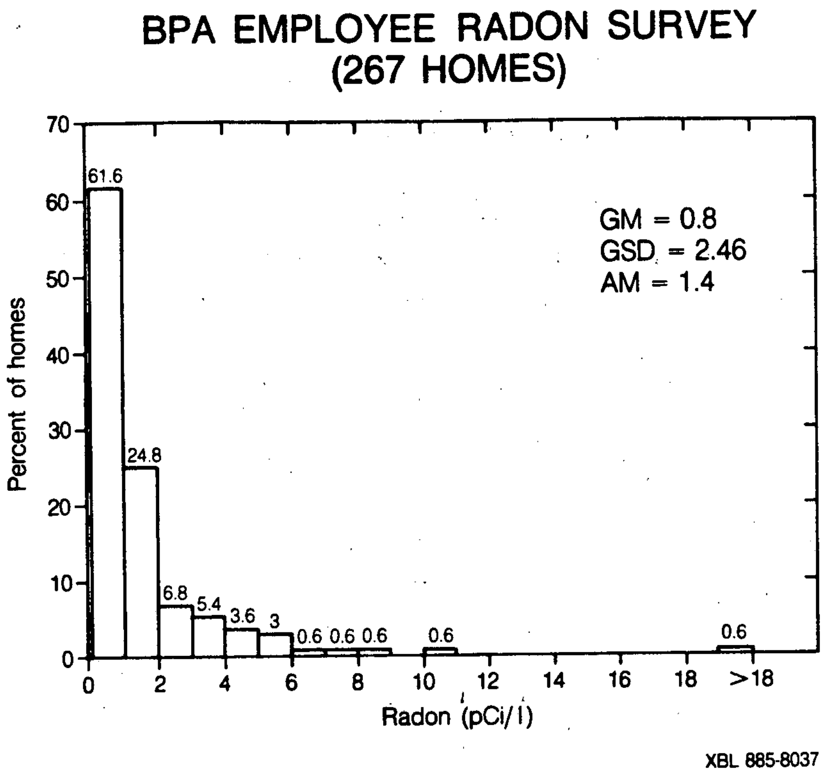

Figure 7 A similar distribution of radon is seen for 267 homes of BPA employees in the Pacific Northwest (from Thor, 1984).

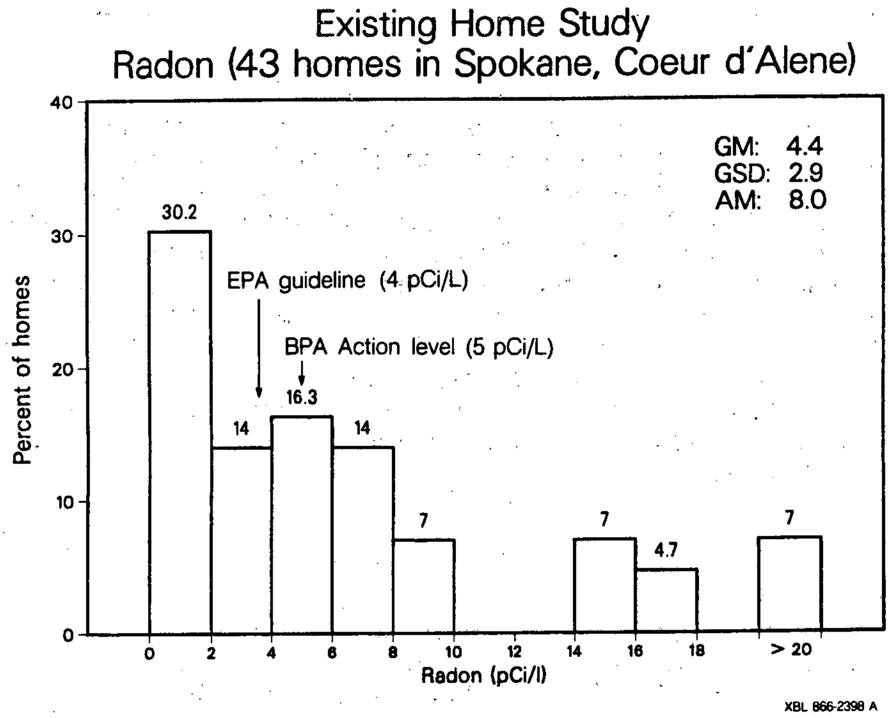

Figure 8 Histogram for 43 of the 111 homes in the screening survey. These structures, located in the Spokane/Veradale/Kootenai county area, have a significantly higher mean radon level and have weighted the tail of the distribution in Figure 5. Subsequent studies have shown that pressure-driven flow of large quantities of radon-laden soil gas through gravelly, highly permeable local soil is the main cause of the elevated levels.

TABLE 7. PHASE 1 SCREENING SURVEY
MAILED PASSIVE SAMPLERS
INDOOR POLLUTANT CONCENTRATION BY REGION

REGION		HCHO (ppb-vol)	NO_2 (ppb-vol)	H_2O VAPOR ($g-H_2O/kg-air$)	RN (pCi/L)
VANCOUVER, WA	GM/AM	38.9 / 43.1	5.2 / 6.1	7.03 / 7.08	1.22 / 1.74
	GSD/ASD	1.6 / 20.1	1.9 / 3.4	1.13 / 0.86	2.20 /
	N	67	68	66	68
SPOKANE, WA	GM/AM	34.0 / 37.8	5.3 / 6.8	5.47 / 5.54	5.51 / 8.50
	GSD/ASD	1.6 / 17.6	2.0 / 5.7	1.18 / 1.02	2.63 /
	N	27	26	25	27
ALL HOMES	GM/AM	37.2 / 41.4	5.3 / 6.3	6.56 / 6.66	1.87 / 3.66
	GSD/ASD	1.6 / 19.5	1.9 / 4.3	1.19 / 1.14	2.95 /
	N	94	94	91	95

Table 9 compares the two screening survey techniques with the pre-weatherization continuous baseline measurements. Both survey techniques are within 30% of the baseline data. Statistical tests of the differences between the means of the test results are inconclusive (one-tailed t-test for paired comparisons: 0.01>P>0.05, one-tailed t-test of the difference between samples of equal size: 0.9>P>0.4). The difference for the alpha track passive monitor survey could be due to the more moderate weather conditions during their fall exposure or to the relatively shorter (and presumably less representative) 7 to 10-day measurement period for the CRM data. The 30-minute CRM survey measurement is, without question, of insufficient duration to be representative. The surprise is that it so closely approximates the longer measurement. A measurement over the short 30-minute period is more likely to fall within a transient low (or high) radon period, since concentrations have been observed to vary by a factor of 10 in a 6-hour period (Turk *et al.*, 1987).

Nitrogen Dioxide.

As expected, indoor nitrogen dioxide concentrations (Figure 9) were low (geometric mean of 5.1 ppb), since most homes did not have unvented combustion appliances. The maximum observed concentration was 28 ppb, in Spokane. The higher indoor levels observed are probably due to indoor combustion sources. Measured concentrations in both regions were comparable as seen in Table 7 (geometric means of 5.2 vs. 5.3 ppb).

TABLE 8. PHASE 1 SCREENING SURVEY
MAILED - PASSIVE SAMPLERS
INDOOR POLLUTANT CONCENTRATION BY SUBSTRUCTURE TYPE

SUBSTRUCTURE		HCHO (ppb-vol)	NO_2 (ppb-vol)	H_2O VAPOR (g H_2O/kg-air)	RN (pCi/L)
BASEMENT ONLY	GM/AM	32.9 / 36.4	5.3 / 6.2	5.93 / 6.01	2.73 / 5.07
	GSD/ASD	1.6 / 16.6	1.8 / 3.6	1.18 / 0.99	3.27 /
	N	34	34	34	34
CRAWLSPACE ONLY	GM/AM	40.3 / 45.0	5.5 / 6.4	7.42 / 7.48	1.40 / 1.97
	GSD/ASD	1.6 / 22.9	1.8 / 3.4	1.13 / 0.94	2.20 /
	N	31	30	29	31
SLAB ONLY	GM/AM	39.6 / 41.5	6.3 / 6.5	7.25 / 7.30	2.08 / 2.75
	GSD/ASD	1.4 / 14.5	1.3 / 1.7	1.14 / 1.00	2.43 /
	N	4	4	4	4
BASEMENT + CRAWL	GM/AM	33.4 / 39.0	6.2 / 8.1	6.33 / 6.38	2.03 / 6.06
	GSD/ASD	1.8 / 19.9	2.1 / 7.2	1.15 / 0.85	4.00 /
	N	11	12	10	12
BSMT OR CRAWL + SLAB	GM/AM	45.7 / 48.4	3.8 / 4.9	6.47 / 6.56	1.28 / 2.16
	GSD/ASD	1.4 / 17.6	2.1 / 3.7	1.19 / 1.02	2.63 /
	N	14	14	14	14
ALL HOMES	GM/AM	37.2 / 41.4	5.3 / 6.3	6.56 / 6.66	1.87 / 3.66
	GSD/ASD	1.6 / 19.5	1.9 / 4.3	1.19 / 1.14	2.95 /
	N	94	94	91	95

Water Vapor.

Indoor water vapor concentrations in the two regions were probably related to the levels in the outdoor air. The average water vapor concentration (Figure 10 and Table 7) of the Vancouver homes was higher (arithmetic mean of 7.1 g/kg*) than that of the Spokane/Coeur d'Alene group (5.5 g/kg), probably due to the coastal influence causing higher outdoor concentrations. Another study of more tightly constructed new homes does not demonstrate such a difference between the same two regions (Turk *et al.*, 1987b). We assume that water vapor concentrations are following a normal distribution and therefore refer to arithmetic means and standard deviations. The apparent elevation of water vapor levels in crawlspace-only homes (Table 8), 7.42 g/kg, is, once again, probably an artifact of the non-uniform distribution of substructure types between the regions. Most of the crawlspace homes are located in the more humid Vancouver area.

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*Water vapor concentrations, as measured by the passive sample, are given in units of absolute humidity, g of water per kg of air. For reference, a concentration of 6.5 g/kg at 70° F (21° C) is equal to 42% relative humidity.

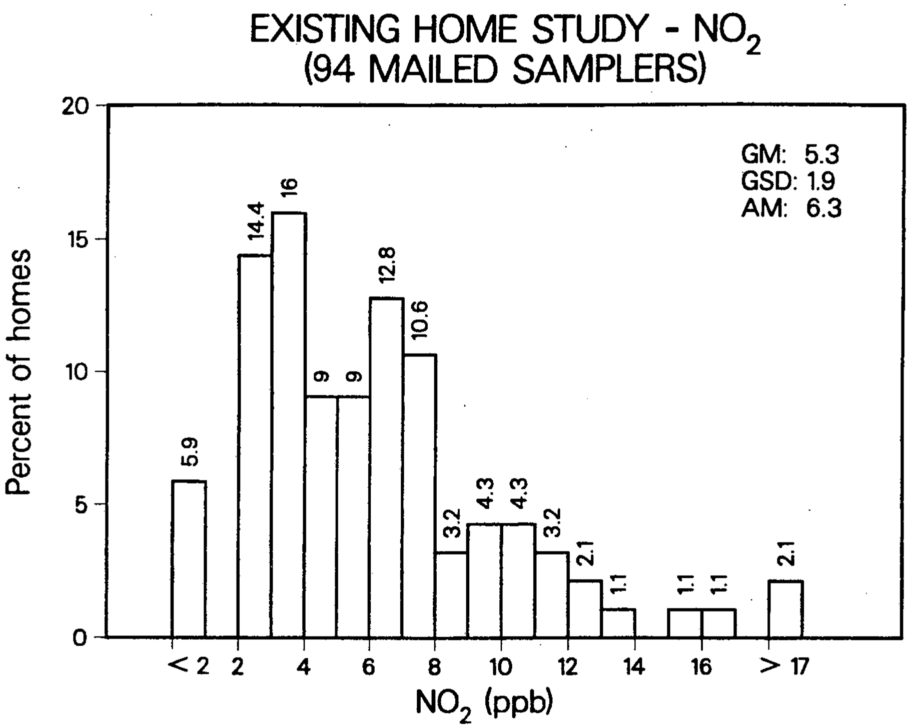

Figure 9 Data from NO_2 passive samplers deployed in 95 homes during screening survey. Concentrations are generally low since few homes had indoor, unvented combustion appliances. The minimum detection limit was 2 ppb.

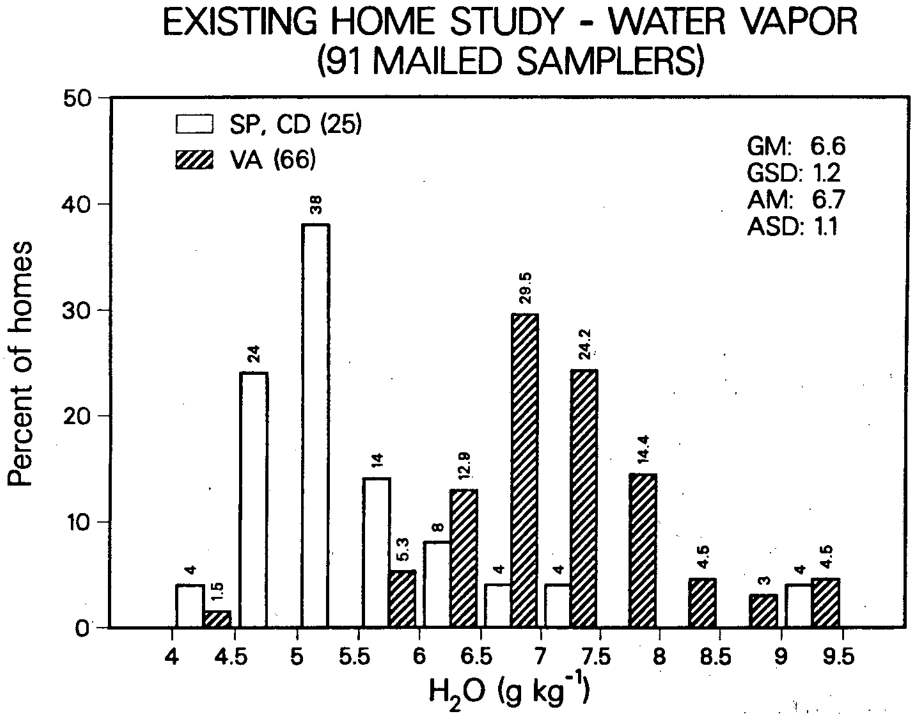

Figure 10 Water vapor concentrations from 91 homes in the screening survey show higher levels in the Vancouver homes (shaded bar), probably related to the higher outdoor concentrations of the the mild coastal climate.

Table 9. Comparison of Screening Survey and Baseline Period Radon Measurements (pCi/L)

	Alpha Track Passive Monitor Screening	CRM Baseline Period
N (Houses)	35	35
Arithmetic Mean	4.16	6.14
Geometric Mean	2.53	3.22
Geometric Standard Deviation	2.61	3.02
	30 min. CRM Screening	**CRM Baseline Period**
N (Houses)	13	13
Arithmetic Mean	16.28	22.87
Geometric Mean	8.65	6.65
Geometric Standard Deviation	3.37	5.26

Formaldehyde.

The geometric mean formaldehyde concentrations for 94 survey homes was quite low at 37.2 ppb (GSD of 1.6). The data are shown in Figure 11. Concentrations from the replicate samplers were averaged for each house. Only one home had a concentration exceeding the ASHRAE 62-1981 guideline of 100 ppb. This house was recently remodeled with new kitchen cabinets which may have been constructed from bonded wood products containing formaldehyde resins. Average concentrations in the two regions were comparable (two-tailed t-test of unequal sample size, $0.4>P>0.2$): Vancouver had a geometric mean of 39 ppb and Spokane/Coeur d'Alene a geometric mean of 34 ppb (Table 7). This differs from results of the study of newly constructed homes (Turk, *et al.* 1987b), where homes in climate zone 1 had significantly higher HCHO levels than those in climate zone 2, possibly due to differences in construction materials. Mean concentrations in the new homes for both regions were higher than in these older existing homes. Table 10 and Figure 11 show the tendency for lower HCHO levels in older homes for this group of buildings.

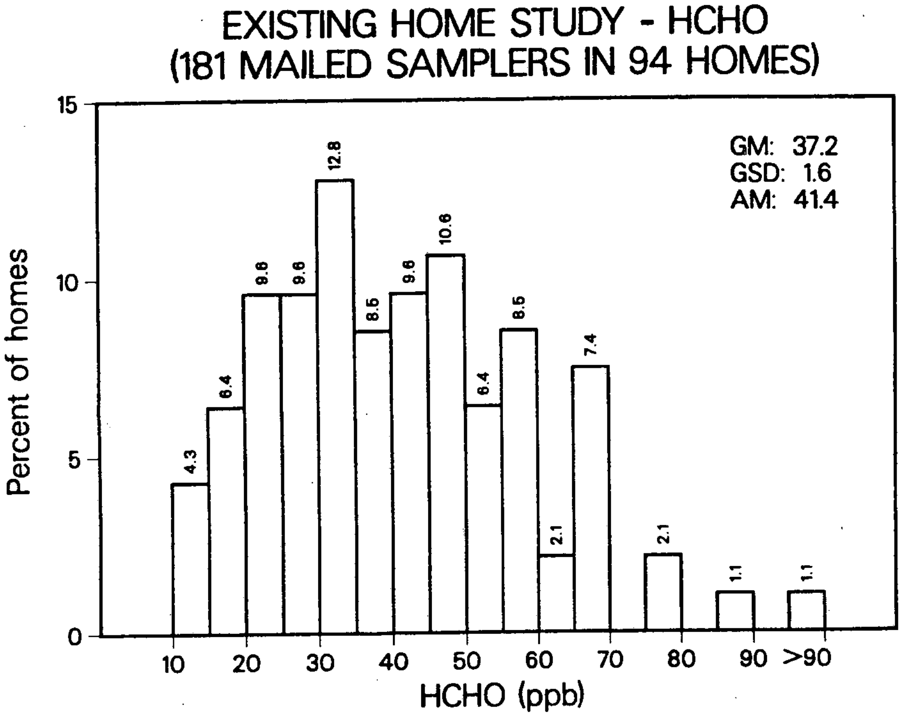

Figure 11 Formaldehyde data from 94 homes in the survey. The mean concentration for all homes was quite low with only one home recording a concentration greater than the 100 ppb guideline from ASHRAE 62-1981 (136 ppb). The minimum detection limit is 11 ppb.

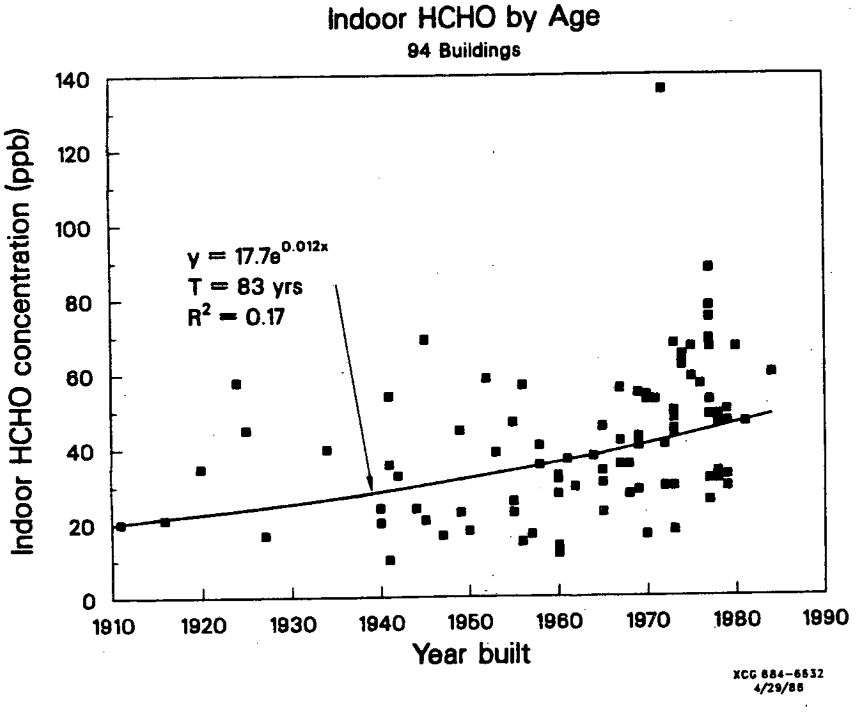

Figure 12 Formaldehyde plotted vs. structure age for 94 survey homes. An exponential was fitted to the data to account for the lower HCHO in older structures, assuming that exhaustion of free HCHO in UF-bonded wood products is the main cause. The fit is poor, suggesting other influences such as quantity of UF-bonded wood products, ventilation rate, temperature, and humidity.

TABLE 10. PHASE 1 SCREENING SURVEY
MAILED PASSIVE SAMPLERS
INDOOR POLLUTANT CONCENTRATION BY AGE OF HOME

AGE OF HOUSE (YEARS)		HCHO (ppb)	NO_2 (ppb)	H_2O VAPOR ($g\text{-}H_2O/kg\text{-}air$)	RN (pCi/L)
1-10	GM/AM	49.6 / 52.2	4 / 5	6.21 / 6.29	2.64 / 5.72
	GSD/ASD	1.4 / 16.6	2.0 / 3.1	1.17 / 1.01	3.45 /
	N	26	26	25	26
11-20	GM/AM	40.9 / 44.8	6 / 7	7.01 / 7.09	1.60 / 2.99
	GSD/ASD	1.5 / 22.1	2.1 / 5.6	1.17 / 1.05	2.95 /
	N	29	29	27	29
21-30	GM/AM	29.4 / 32.2	6 / 7	6.64 / 6.78	2.03 / 3.87
	GSD/ASD	1.6 / 13.6	1.6 / 4.0	1.23 / 1.38	3.00 /
	N	18	17	17	18
31+	GM/AM	28.6 / 31.9	6 / 6	6.38 / 6.47	1.43 / 1.93
	GSD/ASD	1.6 / 15.5	1.5 / 2.5	1.19 / 1.06	2.20 /
	N	21	22	22	22
ALL HOMES	GM/AM	37.2 / 41.4	5 / 6	6.56 / 6.66	1.87 / 3.66
	GSD/ASD	1.6 / 19.5	1.9 / 4.3	1.19 / 1.14	2.95 /
	N	94	94	91	95

Figure 12 displays the concentration of formaldehyde as a function of the year of construction for 94 houses in the survey. An exponential function was fitted to the data and a decay time constant was calculated.

$$C = C_O e^{-\gamma t}, \qquad [1]$$

where

C = measured concentration (ppb),

C_O = initial concentration (ppb),

$\gamma = \frac{1}{T}$, T = time constant (years),

t = time interval from construction of building.

For these data, T was determined to be 83 years, very much longer than that seen in the study of 35 Portland-area new homes (T = 16.5 years). However, the R^2 of 0.17 indicates that the correlation of age and HCHO concentrations in the older homes is not strong.

Concentrations in newer homes may, 1) be higher because of the greater use of formaldehyde-releasing materials (primarily pressed-wood products), and lower ventilation rates due to tighter construction; and 2) may demonstrate a shorter decay constant because of the higher off-gassing rate of free formaldehyde from newer construction materials (Meyer and Hermanns, 1984).

Matthews *et al.* (1986) have shown the effect of elevated temperatures and humidity on increased HCHO release rates from urea formaldehyde-bonded wood products. Therefore, the difference in indoor water vapor concentrations between the two regions might be expected to have caused a related difference in indoor HCHO levels. While we have already observed that this difference is not pronounced, Figure 13 displays a very weak relationship between indoor water vapor and HCHO. A more comprehensive model of HCHO as a function of temperature, humidity, and ventilation rate is discussed in the next section.

B. WEATHERIZATION SENSITIVITY

Data and results from the different measurements before adjustments for environmental conditions are presented and discussed below. Final sections discuss attempts to normalize and model these data.

Building Tightness.

Blower door tests were conducted on all homes after large openings (fireplaces, flues, vents, etc.) had been sealed with tape or plastic. By sealing these large openings each time the test was run, small changes in leakage area due to weatherization or other effects would not be swamped by the large areas of the sealed openings. The effective leakage area (ELA) was calculated at 4 Pa from a power curve fit to higher pressure data.

Specific leakage area (SLA) is defined as the ELA (in cm^2) of the building shell normalized by the occupied floor area of the house (in m^2) and is useful in making inter-house comparisons. The SLA data here do not include those leakage areas sealed during the blower test. Figure 14 is a histogram of the baseline (pre-weatherization) SLA measurements for the 40 study homes and initial period measurements for the eight control homes. The SLA data suggest that it can be reasonably represented by a lognormal distribution. The geometric mean SLA is 5.1 cm^2/m^2 (GSD of 1.65) for the 40 study homes and 4.77 cm^2/m^2 (GSD of 1.59) for the eight control homes. When segregated by region, the Spokane/Coeur d'Alene study houses are modestly tighter, on average (with a geometric mean of 4.93 cm^2/m^2) than their Vancouver counterparts (5.31 cm^2/m^2) (Table 11), but the difference is not significant (two-tailed t-test $0.9>P>0.5$). The difference is probably due to the influence of the more severe inland climate that encourages construction of tighter houses for comfort and energy conservation cost considerations. Spokane/Coeur d'Alene control homes had a mean SLA of 4.53 cm^2/m^2 while Vancouver control homes had a mean of 5.18 cm^2/m^2, very similar to that for the study homes. Baseline and initial test period SLA measurements ranged from 1.99 to 24.48 cm^2/m^2 in Spokane/Coeur d'Alene and from 3.7 to 12.06 cm^2/m^2 in Vancouver. The values measured here are within the range typically observed for the existing U.S. housing stock -- four to ten cm^2/m^2 (Grimsrud *et al.*, 1983).

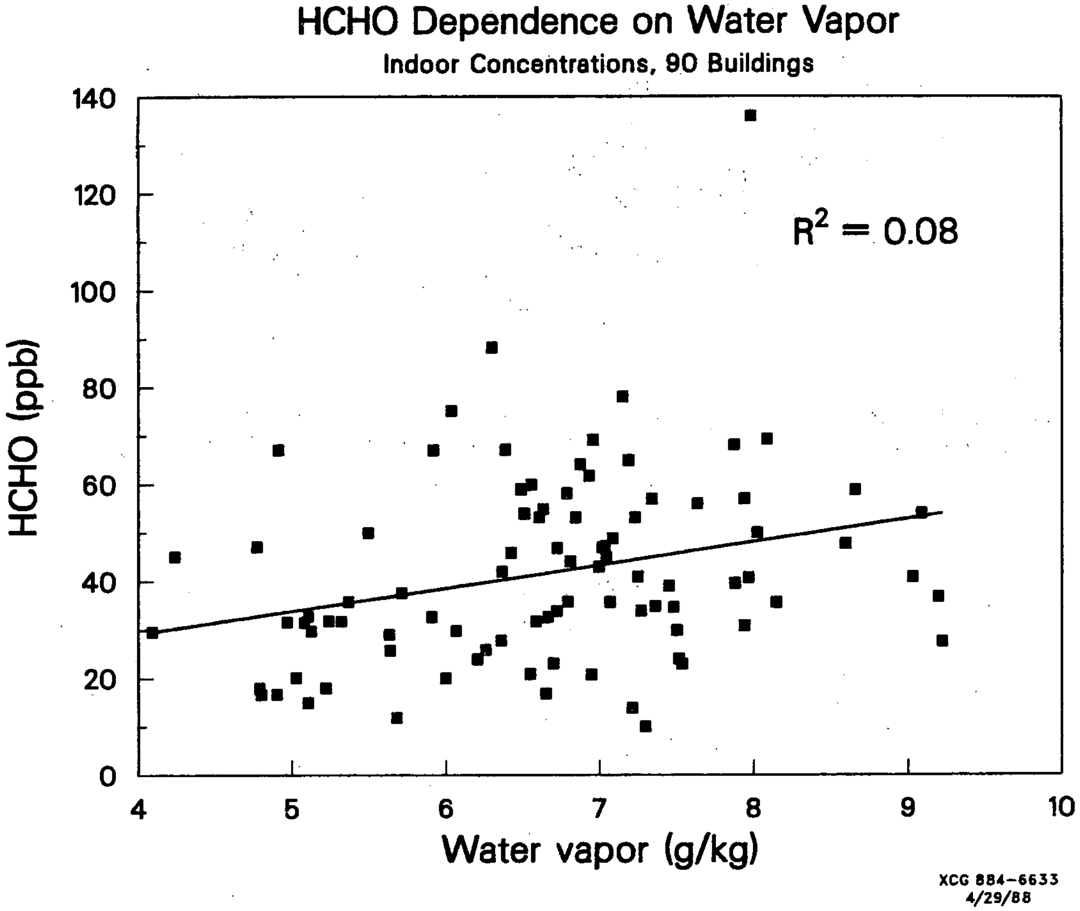

Figure 13 Testing the dependence of indoor HCHO concentrations on indoor water vapor levels in 90 survey homes shows poor correspondence. Agreement was much better for a group of new homes (Turk et al., 1987b) that may include more UF-bonded wood construction materials that are more sensitive to changes in humidity levels.

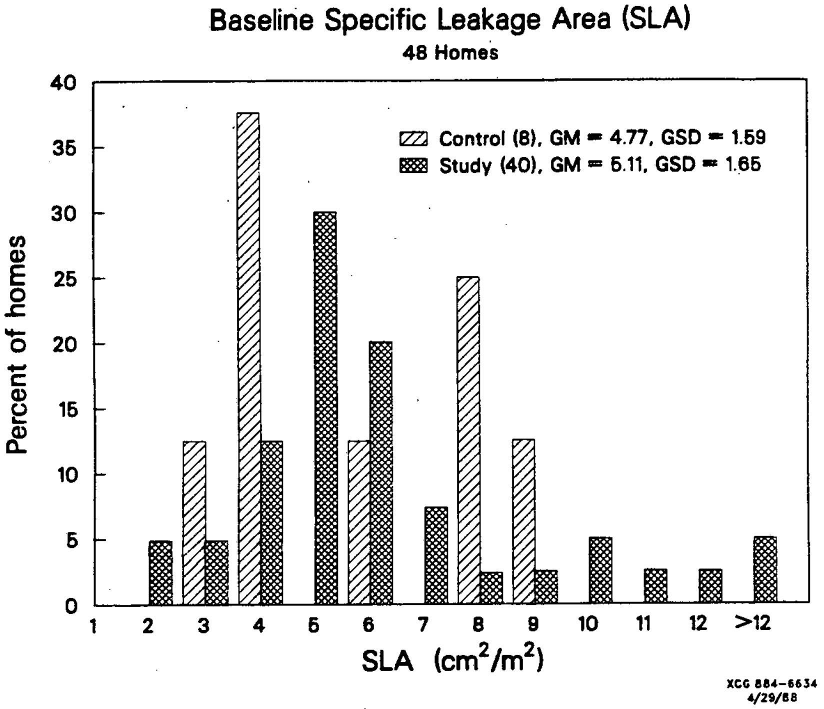

Figure 14 Histogram of baseline (pre-weatherization) SLA values for the 40 study homes and for the initial measurement period in the eight control homes. The mean SLA is within the range for existing U.S. housing.

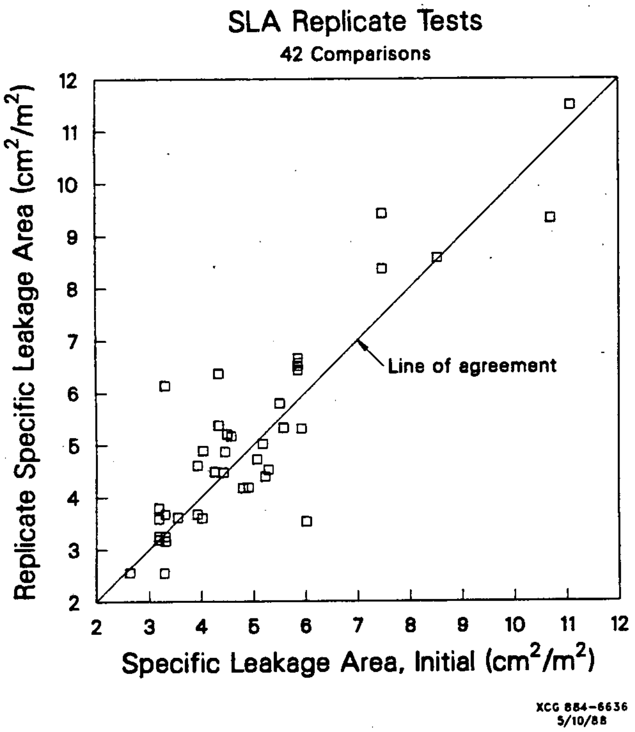

Figure 15 Replication between 42 pairs of SLA tests from 25 homes is good with most points on or near the line of agreement. The tests were conducted on separate days without deliberate changes to the house leakage area.

PHASE 2 - WEATHERIZATION SENSITIVITY

TABLE 11. EFFECT OF WEATHERIZATION ON SPECIFIC LEAKAGE AREA (SLA)

(CM^2/M^2 @ 4PA)

	BPA WEATHERIZATION			WEATHERIZATION + WALL INSULATION			WEATHERIZATION W/O WALL INSULATION			WEATHERIZATION + HOUSE DOCTOR			WEATHERIZATION + WALL INSULATION + HOUSE DOCTOR		
REGION AND TEST PERIOD	GM	GSD	NO	GM	GSD	NO	GM	GSD	NO	GM	GSD	NO	GM	GSD	NO
ALL HOMES															
BASELINE (BSL)	5.11	1.65	40	6.29	1.68	14	4.58	1.58	26	6.52	2.19	5	7.40	2.32	4
POSTWALL (PWL)				5.89	1.66	14							6.52	2.04	4
% _ FROM BSL/P				6.4/<0.2									11.9/<0.2		
POSTWEATHERIZATION (PWX)	4.47	1.59	40	5.46	1.61	14	4.02	1.54	26	5.28	1.82	5	5.77	1.92	4
% _ FROM BSL/P	12.5/<0.005			13.2/<0.1			12.2/<0.01			19.0/<0.2			22.0/<0.2		
% _ FROM PWL/P				7.3/<0.05									11.5/<0.1		
POST HOUSE DOCTOR (PHD)										3.93	1.66	5	4.43	1.64	4
% _ FROM BSL/P										39.7/<0.1			40.1/<0.2		
% _ FROM PWL/P													32.1/<0.2		
% _ FROM PWX/P										25.6/<0.1			23.2/<0.2		
SPOKANE/COEUR D'ALENE															
BASELINE (BSL)	4.93	1.85	20	7.17	1.76	8	3.84	1.70	12	12.86	2.48	2	12.86	2.48	2
POSTWALL (DWL)				6.33	1.75	8							10.01	2.28	2
% _ FROM BSL/P				11.7/<0.2									22.2/<0.2		
POSTWEATHERIZATION (PWX)	4.11	1.72	20	5.94	1.75	8	3.22	1.47	12	8.47	2.24	2	8.47	2.24	2
% _ FROM BSL/P	16.6/<0.025			17.2/<0.2			16.1/<0.05			34.1/<0.2			34.1/<0.2		
% _ FROM PWL/P				6.2/<0.2									15.4/<0.2		
POST HOUSE DOCTOR (PHD)										5.73	1.89	2	5.73	1.89	2
% _ FROM BSL/P										55.4/<0.2			55.4/<0.2		
% _ FROM PWL/P										-			42.8/<0.2		
% _ FROM PWX/P										32.3/<0.2			32.3/<0.2		
VANCOUVER															
BASELINE (BSL)	5.31	1.43	20	5.28	1.54	6	5.32	1.41	14	4.14	1.24	3	4.26	1.34	2
POSTWALL (PWL)				5.35	1.60	6							4.24	1.37	2
% _ FROM BSL/P				-1.3/<0.25									0.5/>0.45		
POSTWEATHERIZATION (PWX)	4.86	1.44	20	4.87	1.42	6	4.86	1.46	14	3.86	1.16	3	3.94	1.22	2
% _ FROM BSL/P	8.5/<0.01			7.8/<0.2			8.6/<0.025			6.8/<0.2			7.5/<0.25		
% _ FROM PWL/P				9.0/<0.2									7.1/<0.45		
POST HOUSE DOCTOR (PHD)										3.06	1.31	3	3.43	1.28	2
% _ FROM BSL/P										26.1/<0.05			19.5/<0.2		
% _ FROM PWL/P										-			19.1/<0.2		
% _ FROM PWX/P										20.7/<0.1			12.9/<0.05		

GM = GEOMETRIC MEAN   GSD = GEOMETRIC STANDARD DEVIATION   P = PROBABILITY OF EQUAL MEANS HAVING % _ AS NOTED   NO = NUMBER OF HOUSES IN AVERAGE

Replicate blower door tests were conducted in 25 homes on separate days without deliberate changes to the leakage area. Forty-two paired leakage area tests are shown in Figure 15. The line shown is the line of agreement. Replication is good, with most points on or near the line of agreement. Out of the 42 tests, there were 31 unique conditions, meaning that nine tests were additional replicates. The mean coefficient of variation for the 31 replicate conditions was 10.3%. This result implies that the total variation caused by changes in an individual house leakage area and blower door test imprecision is approximately 10%.

A detailed examination of the effects of weatherization on air infiltration leakage is presented in Table 11. An attempt was made to isolate progressive reductions in SLA resulting from staged weatherization. The columns in Table 11 define categories of weatherization previously described and are segregated further by climatic region and the measurement periods following the various stages of weatherization. Mean SLA values are calculated for each cluster. The percent change in SLA from previous test period conditions is included along with the probability of equal means for different periods having the percent change that is indicated. In other words, the probability indicates whether the difference of the mean SLA's is significant. Clusters with larger numbers of homes have better statistical resolving power between differences. The statistical test was computed by using a one-tailed t-test for paired comparisons (Sokal and Rohlf, 1981).

Changes in the mean SLA from baseline conditions due to BPA standard weatherization are compared in column 1 of Table 11. For all 40 homes this reduction was 12.5%, and is statistically significant at the 0.005 level. This includes any changes caused by the addition of wall insulation in 14 homes. Figure 16 shows the shift in the distribution of SLA after the weatherization. Changes in Spokane/Coeur d'Alene homes were 16.6% and in the Vancouver homes 8.5%, both statistically significant at less than the 0.025 level. Following weatherization, the ranges of SLA for Spokane/Coeur d'Alene and Vancouver were 1.90 to 14.95 cm^2/m^2 and 3.02 to 11.90 cm^2/m^2 respectively.

The addition of wall insulation alone (illustrated in column 2) reduced the average SLA approximately 6.4%. However, the difference is not acceptably significant ($P<0.2$), possibly because there were few homes in this cluster. Since most insulation that is blown into wall cavities starts as a loose or shredded material and is not usually compacted into the cavity, its ability to inhibit air leakage into and out of the building may be limited. Consequently, a small reduction or no reduction in SLA is not surprising. The incremental reduction in SLA from post-wall insulation to post-weatherization was 7.3% and of moderate significance ($P<0.05$). In those homes without wall insulation (column 3), the SLA dropped 12.2% ($P<0.01$) after standard weatherization without the benefit of tightening due to wall insulation.

House doctoring plus standard weatherization (column 4) reduced SLA's an average of 39.7% ($P<0.1$) for the five homes that participated in this weatherization measure. By itself, house doctoring caused a reduction of 25.6% ($P<0.1$) after standard weatherization. Due to the small numbers of houses undergoing this weatherization treatment, these percentage reductions are marginally significant. Using a blower door to pressurize/depressurize the structure during the retrofit, the contractor was able to identify leakage sites for sealing and to conduct a pre- and post-retrofit ELA measurement. Apparently, the goal of reducing ELA by 30% with the house doctor retrofits alone was close to being achieved. The range of SLA values for baseline conditions in the five homes that were house doctored were 3.46 to 24.48 cm^2/m^2. Following house doctoring the range was 2.88 to 8.98 cm^2/m^2. A study by Nagda *et al.* (1985) of two matched houses showed that measured ventilation rates were reduced 24% and ELA was reduced 40% following intensive weatherization (similar to a house doctor retrofit) of the experimental houses.

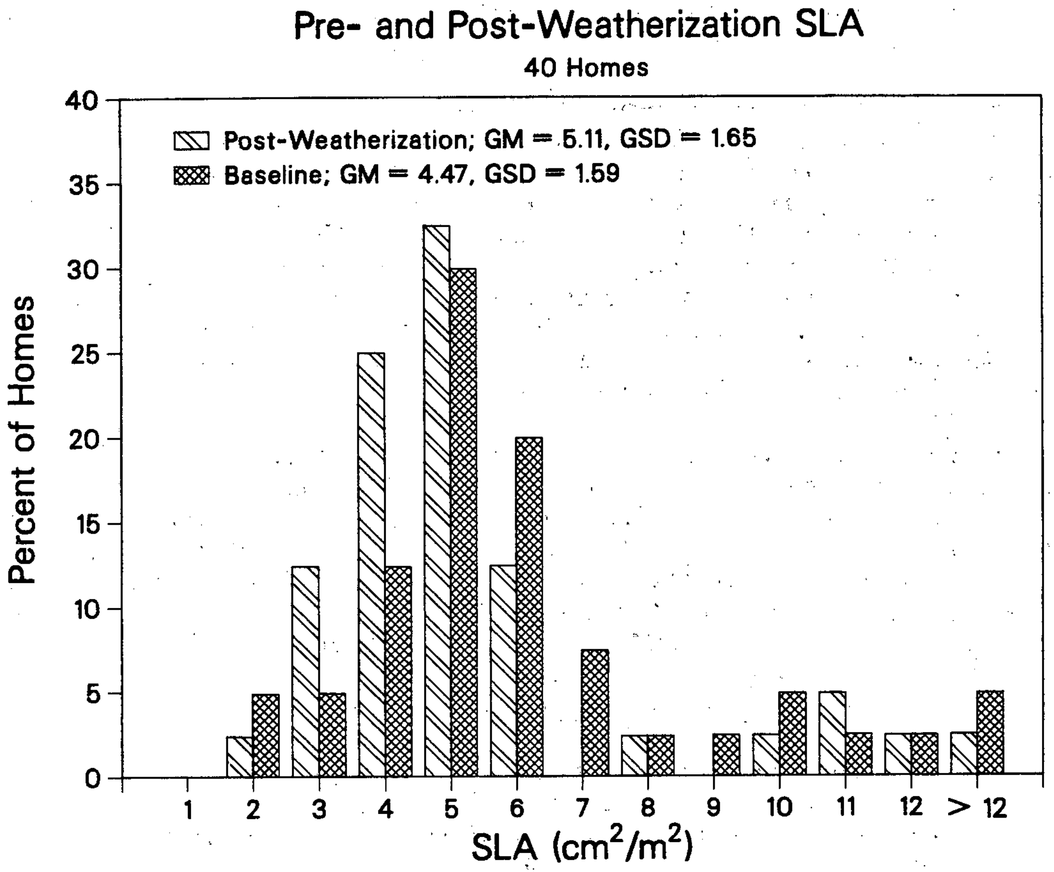

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Figure 16 Before and after weatherization SLA for the 40 study homes. Post-weatherization leakage area reductions also include the small effect from the addition of the wall insulation to 14 homes.

Ventilation rates.

Ventilation rates were predicted for each house assuming no occupancy using a model by Sherman and Grimsrud (1980) that incorporates building characteristics (including the ELA measured with the blower door), shielding and terrain coefficients, and environmental conditions for the period. Occupant diaries were used to estimate other ventilation related to door and window openings and the use of fans, clothes dryers, woodstoves, fireplaces, etc. (Derochers and Robertson, 1986; Hekmat and Fisk, 1984). A separate ventilation rate was then calculated to account for occupied conditions. These data along with all other test data are shown for each measurement period for each house in Appendix E. Where occupant diaries were missing or incomplete, ventilation rates assuming occupancy were not calculated.

Whole-house PFT ventilation measurement data are also included in Appendix E. These are summarized with the predicted ventilation rates in Tables 12 and 13 and Figures 17-20. In Table 12, ventilation rates for separate weatherization conditions for each house are averaged and then the statistics computed for all house averages. All ventilation rates for each control home are averaged together and then statistics calculated for the house averages. Control home rates are very similar to those of the study homes. Furthermore, the Spokane/Coeur d'Alene and Vancouver homes had approximately equal ventilation rates. These data are uncorrected for environmental conditions that changed during the course of the study and between pre- and post-weatherization periods, therefore, strict comparisons between these periods to determine the effort of weatherization are not meaningful.

Ventilation rate means range from 0.21 to 0.51 building air changes per hour (ACH in h^{-1}) for the PFT measurements. Figure 17 is a histogram of this PFT measurement data for the pre- and post-weatherization periods and for all test periods in the control homes. In Figure 18, PFT ventilation measurements are plotted against the age of the structure. By grouping the houses, 1890 to 1950 (GM = 0.47 h^{-1}, GSD = 1.88), 1950 to 1970 (GM = 0.39 h^{-1}, GSD = 2.34), and 1970 and newer (GM = 0.28 h^{-1}, GSD = 1.79), we find that the newer homes tend to have lower ventilation rates than the older homes. The only statistical significant difference is found between the newest and oldest group (one-tailed t-test, $0.025>P>0.01$), although the comparison withe the middle-aged group is suggestive ($0.2>P>0.1$).

Table 12 reveals that predicted ventilation rates are, on average, greater than the corresponding PFT-measured rates. A systematic bias in constant injection/integrating sampling ventilation measurement systems is predicted in two papers by Sherman and Wilson (1986) and Sherman (1987). The constant injection/integrating sampling ventilation measurement system used by the PFT devices employs a computation scheme to determining ventilation rates that assumes that the average of the inverse of the ventilation rate is equal to the inverse of the average. This is true only if the ventilation rate is constant. If the ventilation rate varies in time, the PFT system underpredicts the true ventilation rate. A paired comparison between ventilation data for 102 test periods is shown in Table 13 and also illustrates the PFT underprediction. Here the geometric mean PFT rate is approximately 20% lower than the predicted unoccupied rate. Sherman estimated the bias to be 20-30% lower based on the natural variation in instantaneous ventilation rates. The effect of variations in the actual ventilation rate is aggravated by a long sampling period, since the inverse of the average tracer concentration (as measured by the PFT sampler) is no longer the true ventilation rate for that period. Figures 19 and 20 display the relatively poor agreement between the two predicted rates and the PFT-measured rates. The bias of the PFT technique is evident. Error bars for one data point are indicated, as well as dashed lines representing ±30% from agreement. This discrepancy between techniques is similar to that observed in the previously mentioned study of Pacific Northwest new homes. Obviously, more work needs to be done to investigate the errors associated with these techniques.

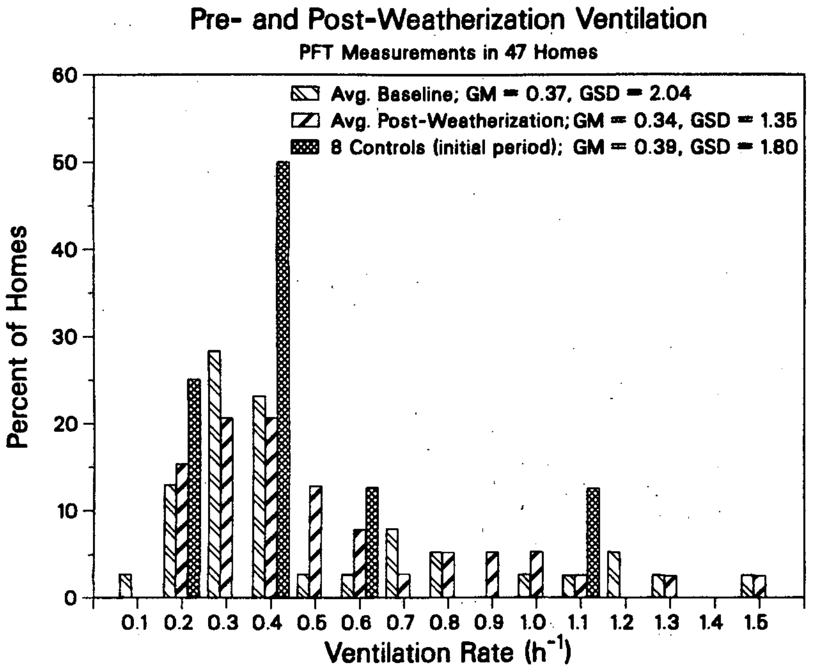

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Figure 17 Distribution of PFT-measured ventilation rates pre- and post-weatherization in 38 homes and in the eight control homes. Data are not corrected for differing environmental conditions during pre-and post-test periods.

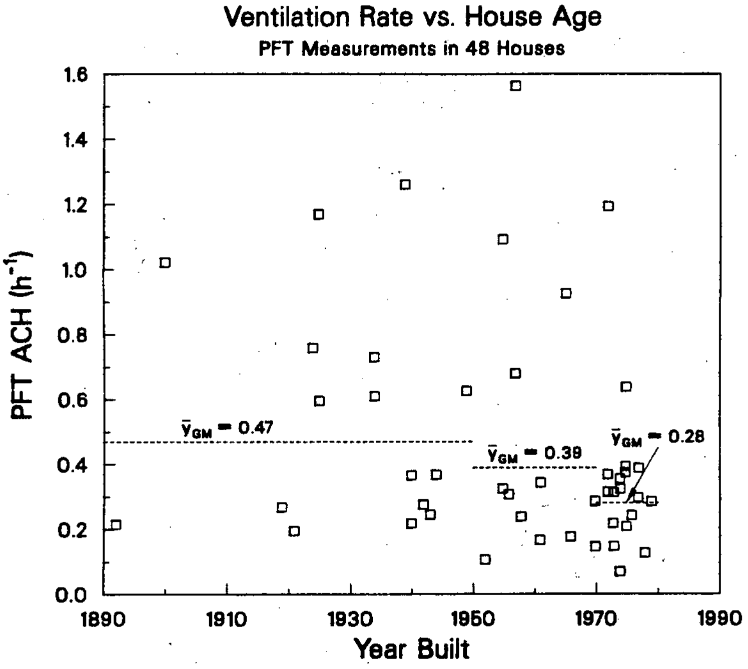

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Figure 18 Initial period PFT measurements vs. age of the structure. In this group of houses, newer structures, >1970, appear to have a slightly lower mean ventilation rate than the two clusters of older houses.

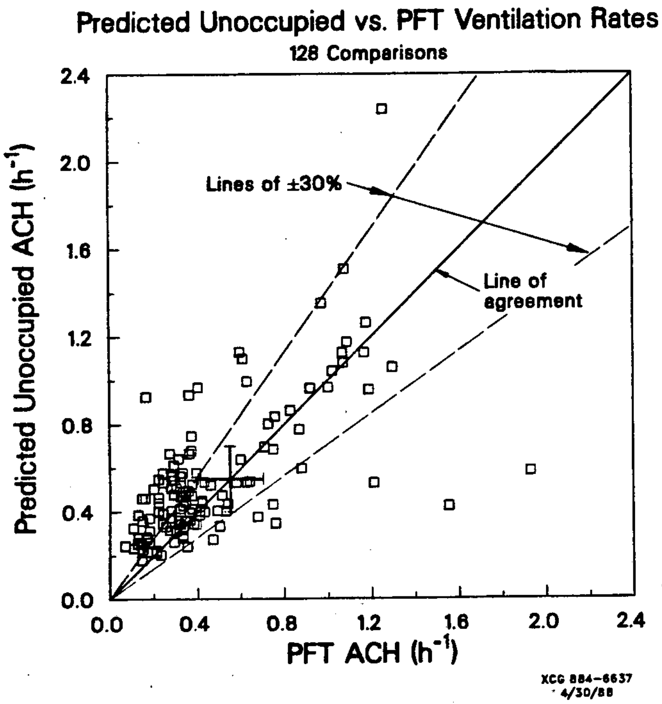

Figure 19 Comparison of 128 predicted ventilation rates, assuming no occupancy, and the PFT-measured ventilation rates. The underprediction bias of the PFT techniques is evident with many points lying above the line of agreement. There is considerable scatter with the error bars indicated for one data point. The dashed lines are ±30% from the line of agreement and should include many of the biased values.

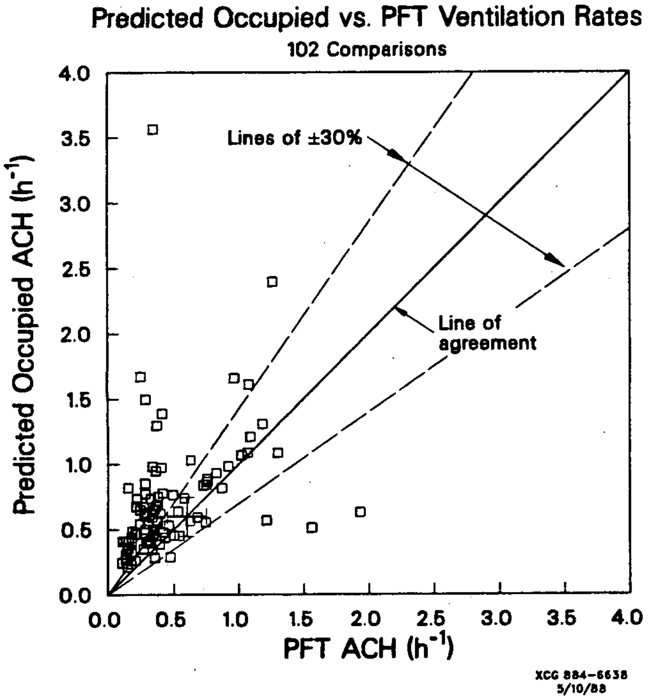

Figure 20 Similar to Figure 19, except the predicted ventilation rates assume occupancy effects. The agreement with the PFT technique is not improved.

PHASE 2 - WEATHERIZATION SENSITIVITY

TABLE 12. VENTILATION RATE SUMMARY
UNCORRECTED FOR ENVIRONMENTAL CONDITIONS

	CONTROL HOMES	SPOKANE/COEUR D'ALENE			VANCOUVER			ALL		
		BASELINE	POST WXTN	POST HD	BASELINE	POST WXTN	POST HD	BASELINE	POST WXTN	POST HD
PREDICTED UNOCCUPIED VENT. (h^{-1})										
ARITHMETIC MEAN	0.67	0.68	0.50	0.59	0.53	0.47	0.28	0.61	0.49	0.40
GEOMETRIC MEAN	0.60	0.59	0.45	0.59	0.49	0.43	0.28	0.54	0.44	0.37
ARITHMETIC STD. DEV.	0.32	0.45	0.27	0.07	0.24	0.23	0.06	0.36	0.24	0.18
GEOMETRIC STD. DEV.	1.62	1.72	1.58	1.13	1.48	1.51	1.24	1.61	1.54	1.56
NO.	22*	20	20	2	20	20	3	40	40	5
PFT MEASURED VENT. (h^{-1})										
ARITHMETIC MEAN	0.43	0.45	0.45	0.52	0.49	0.47	0.25	0.47	0.46	0.36
GEOMETRIC MEAN	0.37	0.34	0.39	0.51	0.39	0.39	0.21	0.37	0.39	0.30
ARITHMETIC STD. DEV.	0.31	0.36	0.25	0.12	0.36	0.31	0.19	0.36	0.28	0.21
GEOMETRIC STD. DEV.	1.82	2.12	1.74	1.27	1.95	1.86	2.11	2.03	1.78	2.08
NO.	30*	20	20	2	20	19	3	40	39	5

*TOTAL NUMBER OF VENTILATION MEASUREMENTS FROM THE 8 CONTROL HOMES

TABLE 13. PHASE 2 - WEATHERIZATION SENSITIVITY VENTILATION RATE DETERMINATION COMPARISON ALL PAIRED DATA (h^{-1})

	PREDICTED VENTILATION		PFT
	OCCUPIED	UNOCCUPIED	MEASURED
ALL PAIRED MEASUREMENTS			
Arithmetic Mean	0.70	0.53	0.46
Geometric Mean	0.60	0.47	0.37
Arithmetic Std. Dev.	0.46	0.31	0.33
Geometric Std. Dev.	1.65	1.59	1.88
No.	102	102	102

Certain necessary assumptions for the PFT technique may be violated in field practice: good tracer mixing, accurate building volumes, proper sampler and tracer source placement, temperature correction for tracer source emission rates, and non-varying ventilation rates. Errors in predicted rates may result from inaccuracies in measured meteorological data, incorrect building volumes, poor estimates of shielding and terrain coefficients, leakage distributions, and occupant effects, assumptions of one zone in the building (particularly in multi-compartmented and multi-storey buildings), and inaccuracies in the leakage area measurement. Until these discrepancies are resolved, the most dependable indication of the effects of house tightening is the leakage area measurement.

While some of the sources of error just mentioned also affect the assumptions of the linear proportionality dependence of ventilation on leakage area, this measurement is a standard technique applicable to most buildings regardless of season or meteorological conditions (with the exception of wind). To determine if weatherization changed ventilation rates, we note that 1) changes in SLA can be measured directly and that remeasurement shows that the results are reproducible, 2) PFT measurements are difficult to interpret because of differences in environmental conditions between the two measurement periods. If they are to be useful as a measure of the change in ventilation rates, they must first be normalized to standard environmental conditions, 3) changes in model predictions (pre- vs. post-weatherization) normalized to standard conditions are essentially changes in pre- and post-weatherization SLA, assuming similar occupancy effects. Therefore, changes in SLA should be a close approximation to the normalized changes in ventilation rate.

Indoor Pollutants.

A summary overview of pollutant concentrations measured during this study is presented in Tables 14 and 15. A more detailed compilation of house and periodic measurement data appears in Appendix E. Carbon monoxide concentrations were usually at or below the detection limit of 2 ppm. Data for this pollutant are summarized separately in Appendix G.

In Table 14, measurement periods for the same weatherization condition on each house are averaged to give mean indoor concentrations for that condition. All indoor samplers in each house were averaged together. The four pollutants are summarized for weatherization and

PHASE 2 - WEATHERIZATION SENSITIVITY

TABLE 14. POLLUTANT CONCENTRATION SUMMARY UNCORRECTED FOR ENVIRONMENTAL CONDITIONS

	SPOKANE/COEUR D'ALENE			VANCOUVER			ALL		
	BASELINE	POST WXTN	POST HD	BASELINE	POST WXTN	POST HD	BASELINE	POST WXTN	POST HD
H_2O (g/kg)									
WXTN HOMES (#):	(20)			(20)			(40)		
AM/OUT	5.53/3.14	6.26/3.90		5.95/3.99	6.45/4.98		5.74/3.56	6.36/4.44	
ASD	0.92	1.24		0.69	0.90		0.83	1.07	
H.D. HOMES (#):	(2)			(3)			(5)		
AM/OUT	5.67/2.41	7.27/4.30	7.72/4.91	6.10/3.53	6.65/5.06	7.56/5.37	5.93/3.08	6.90/4.75	7.63/5.18
ASD	0.46	0.43	0.48	1.05	1.12	1.12	0.81	0.88	0.83
HCHO (PPB)									
WXTN HOMES (#):	(20)			(20)			(40)		
GM	23.2	24.9		36.1	34.8		29.2	29.4	
GSD	1.6	1.7		1.5	1.6		1.7	1.7	
H.D. HOMES (#):	(2)			(3)			(5)		
GM	21.8	33.8	52.9	34.5	33.2	44.2	28.7	33.4	47.5
GSD	1.2	1.6	1.5	1.6	1.4	1.3	1.5	1.4	1.3
NO_2 (PPB)									
WXTN HOMES (#):	(19)			(20)			(39)		
GM/OUT	3.3/5.4	2.9/4.3		3.6/14.7	3.8/12.4		3.5/9.0	3.3/7.4	
GSD	1.7	2.5		1.6	1.9		1.7	2.4	
H.D. HOMES (#):	(2)			(3)			(5)		
GM/OUT	3.1/3.9	4.1/2.7	2.3/1.2	3.8/14.6	3.2/12.5	3.8/10.9	3.5/8.6	3.5/6.8	3.1/4.5
GSD	3.9	4.0	5.7	1.1	1.3	1.7	2.0	2.2	2.7
Rn (pCi/L)									
WXTN HOMES (#):	(19)			(20)			(39)		
GM	7.2	4.7		2.2	1.3		4.2	2.4	
GSD	3.9	4.3		2.4	2.2		3.6	3.7	
H.D. HOMES (#):	(2)			(3)			(5)		
GM	21.7	3.8	3.6	7.1	3.0	2.4	11.1	3.3	2.8
GSD	2.8	1.4	1.7	1.4	2.7	3.8	2.3	2.1	2.7

PHASE 2 - WEATHERIZATION SENSITIVITY

TABLE 15. RSP CONCENTRATION SUMMARY
UNCORRECTED FOR ENVIRONMENTAL CONDITIONS

	SPOKANE/COEUR D'ALENE		VANCOUVER		ALL	
	BASELINE	POST WXTN	BASELINE	POST WXTN	BASELINE	POST WXTN
RSP (ug/m3)						
STUDY HOMES (#):	18	18	17	17	35	35
GM/OUT	30.5/17.9	27.4/15.5	29.5/15.5	24.2/18.6	30.0/24.3	25.8/17.0
GSD	2.2/ 1.8	3.0/ 2.0	2.4/ 1.4	2.3/ 1.6	2.3/ 1.8	2.6/ 1.8
CONTROL HOMES (#):	4	4	2	2	6	6
GM/OUT	15.4/30.4	12.6/25.5	16.7/50.7	10.0/7.8	15.9/36.0	11.7/17.2
GSD	1.9/ 2.0	2.2/ 1.4	1.5/ 1.3	1.1/1.0	1.7/ 1.8	1.9/ 2.0

house doctor homes and for differing climatic regions. From the screening survey, an appropriate sample distribution is chosen for each pollutant. A lognormal distribution waschosen for HCHO, radon, NO_2, and RSP. The normal distribution was chosen for water vapor. A normal distribution describes the water vapor results best, because the width of the distribution is narrower than the mean value. Thus, the probability of finding a zero value is vanishingly small. On the other hand, the width of the distributions for RSP, NO_2, HCHO, and radon are comparable with the median value. This observation, together with the fact that a large value of each of these concentrations is possible, suggests that a lognormal distribution is the appropriate representation.

Water Vapor.

As observed in the screening survey, outdoor and indoor water vapor levels are usually higher in the Vancouver homes. Figure 21 is a distribution of initial period indoor water vapor measurements. Control home concentrations averaged lower than for the study homes, possibly because five of the eight homes were from the drier Spokane/Coeur d'Alene area. The outdoor levels increased during the course of this study, as indicated by the averages for baseline, post-weatherization, and post-house doctor. Indoor concentrations responded also by increasing. The possible effect of weatherization on this change is discussed later.

Figure 22 shows the strong dependence of indoor concentrations on outdoor levels ($R^2 = 0.42$). For this figure, data were also included from a subsequent study, during 1985-86, of radon mitigation techniques (Turk *et al.*, 1987). Data are from homes that participated in this study and continued with the following study without any changes to their structure. The unexplained variation (58%) in indoor levels could be due to water storage by the structure, indoor H_2O vapor sources, and efforts of occupants to control the indoor humidity levels.

Converting water vapor concentrations to relative humidities assuming indoor temperatures of 20°C, the Spokane/Coeur d'Alene average baseline relative humidity would be 37% and Vancouver relative humidity would be 40%. Assuming the temperature to be approximately

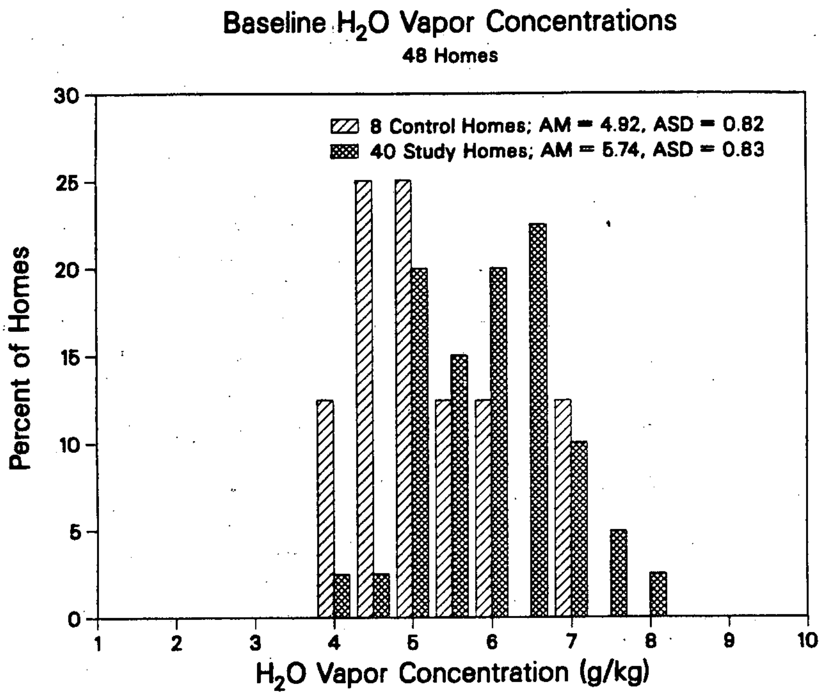

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Figure 21 Indoor water vapor concentrations from the 48 homes participating in the measurements during the initial test period.

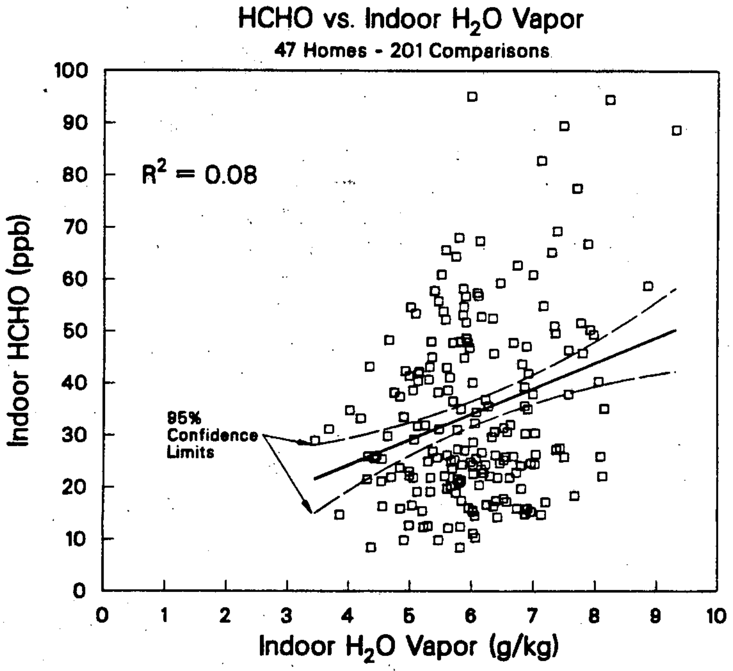

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Figure 22 Forty-two percent of the variation in indoor H_2O vapor levels is explained by variation in outdoor levels in 201 comparisons for 47 homes. 95% confidence limits for regression line are shown. Additional data from some of the same homes participating in a follow-up study were included to increase robustness of regression.

constant for the post-weatherization period, indoor relative humidities would be 42% and 44% respectively.

Formaldehyde.

Baseline formaldehyde concentrations for the 48 homes are displayed in Figure 23. Mean concentrations were quite low (29.2 ppb). Average formaldehyde concentrations range from below detection (11 ppb) to 67 ppb in Spokane/Coeur d'Alene and from 15 to 80 ppb in Vancouver for the baseline measurement period. Post-weatherization concentrations range from below detection to 89 ppb in Spokane/Coeur d'Alene and from 16 to 87 ppb in Vancouver. Outdoor HCHO had a geometric mean of 6.9 ppb for the baseline and 4.6 ppb post-weatherization period for all 40 homes. Many measurements outdoors were less than the detection limit, with wide variations detected, as indicated by geometric standard deviation of 2.3 (baseline) and 2.7 (post-weatherization) respectively. Five baseline and two post-weatherization outdoor values were greater than 15 ppb. Outdoor concentrations have been reported in other studies to vary from 4 to 50 ppb (NAS, 1981). Indoor HCHO concentrations are also higher in Vancouver than in Spokane/Coeur d'Alene during both the baseline and post-weatherization periods (36.1 ppb vs. 23.2 ppb, 34.8 ppb vs. 24.9), although changes between the two periods were slight. In the house-doctored homes, HCHO concentrations appeared to increase dramatically, possibly due to the corresponding increase in indoor relative humidity.

The dependence of HCHO on indoor H_2O vapor levels is plotted in Figure 24 using the expanded data set of Figure 22. As in the screening survey, the correlation is very poor. The same explanation may apply, i.e., in these older homes smaller amounts of UF-bonded construction materials were used, and the free HCHO has been depleted from those materials that were installed.

Nitrogen Dioxide.

NO_2 was, on average, always higher outside than inside, because the homes had few, if any, combustion appliances. One exception, ECD 146, had a kerosene heater in use during the baseline period (but not after weatherization), and was not included in the calculation of the means. Outdoor concentrations in Vancouver were higher than those in Spokane/Coeur d'Alene, but this is not necessarily reflected in the indoor levels. Most were near or only slightly above detection limits of 2 ppb. In the 40 study homes, baseline concentrations had a geometric mean of 3.5 ppb and ranged from 1.0 to 15.7 ppb in all test periods. An outdoor concentration of up to 40 ppb was observed outside one Vancouver home. The indoor concentrations are typical of levels in studies of other electrically-heated homes. For example, in a survey of 24 Wisconsin homes, NO_2 levels were approximately 3 to 5 ppb indoors and 7 ppb outdoors (Spengler *et al.*, 1983).

To test the response of indoor levels to outdoor concentrations, average indoor concentrations from homes without tobacco smoking were compared against the outdoor concentrations (Figure 25). The R^2 is less than 0.03 for that regression. Indoor concentrations remain low, regardless of the outdoor concentration.

Respirable Suspended Particles

Figure 26 is a histogram of indoor and outdoor RSP concentrations from the baseline measurement periods. Tables 14 and 15 are summaries of actual measured values. The data are uncorrected for environmental conditions changing between the pre- and post-weatherization conditions. The three weatherization periods (baseline, post-weatherization, and post-house doctor) generally occurred during different times of the year. The baseline monitoring typically was conducted in mid-winter, post-weatherization in mid-winter to spring, and post house-doctoring during the spring. As true also for Table 12 summarizing

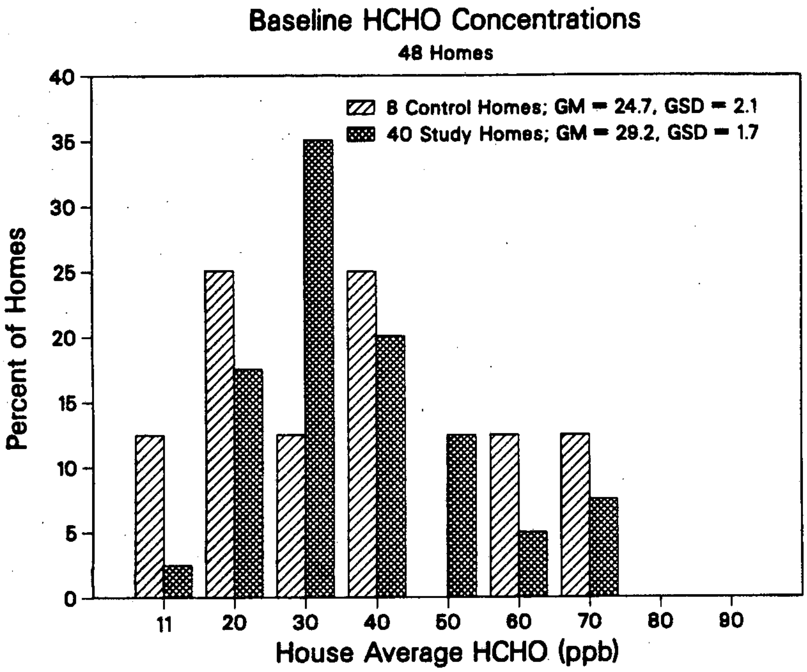

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Figure 23 Histogram of baseline indoor HCHO concentrations from the 48 homes. Concentrations were generally very low.

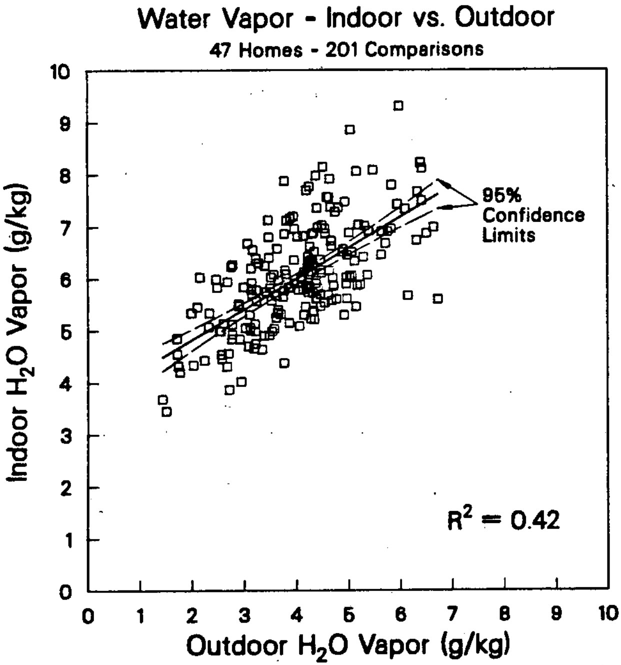

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Figure 24 Using the same expanded data set as Figure 22, indoor HCHO levels are compared with indoor H_2O vapor levels. The dependence is very poor and can possibly be explained by smaller quantities of HCHO-emitting materials and/or earlier depletion of free HCHO from those materials.

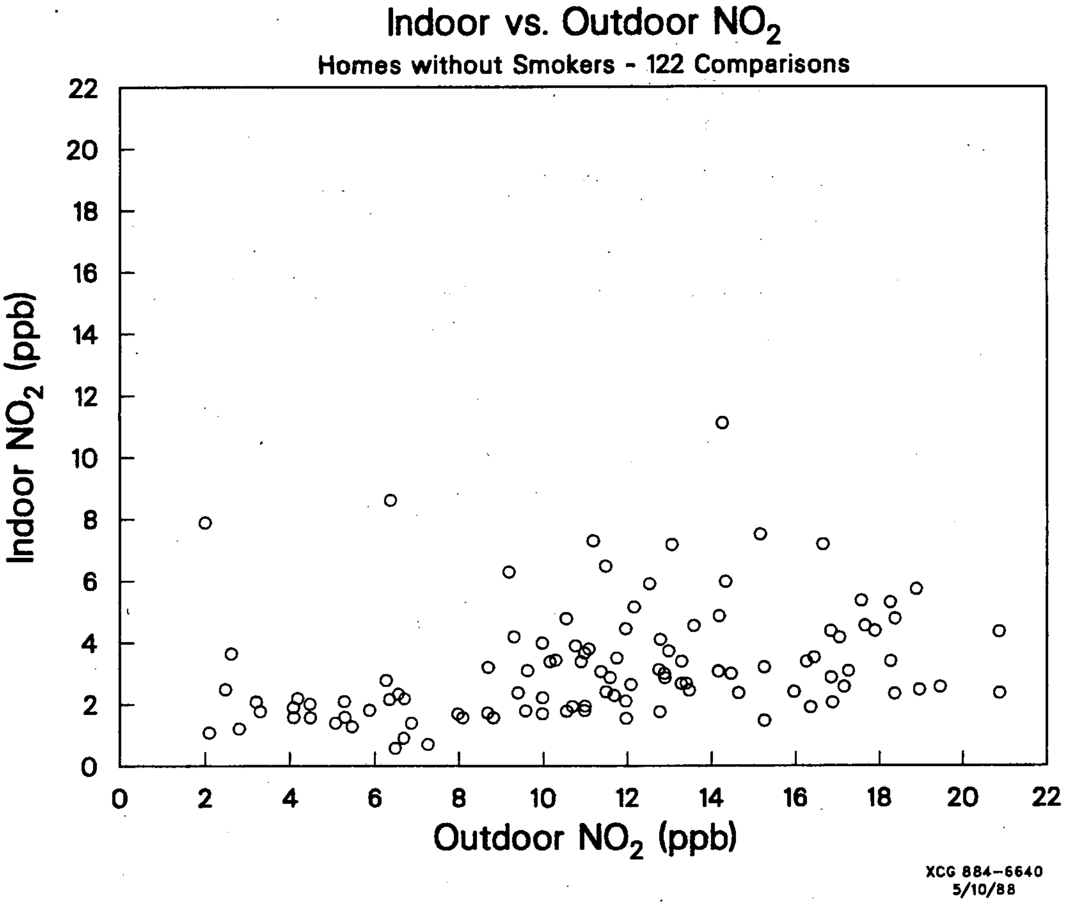

Figure 25 Indoor NO_2 concentrations vs. outdoor concentrations shows that indoor levels remain low even when outdoor concentrations are elevated. Homes without tobacco smoking were used here to simplify the comparisons by minimizing the indoor sources.

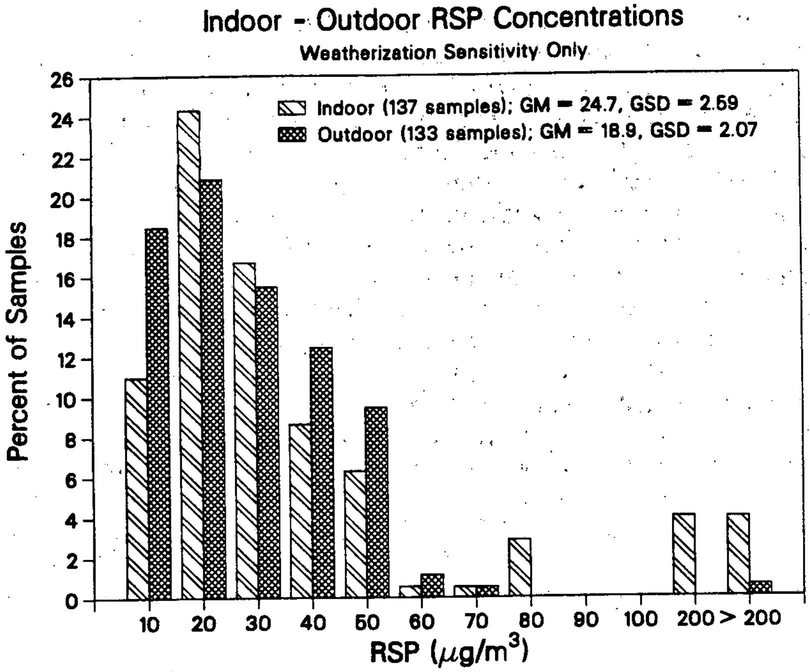

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Figure 26 Histogram of indoor and outdoor RSP concentrations from various test periods throughout the study. Indoor levels had a higher mean, due primarily to those homes with occupants who smoked.

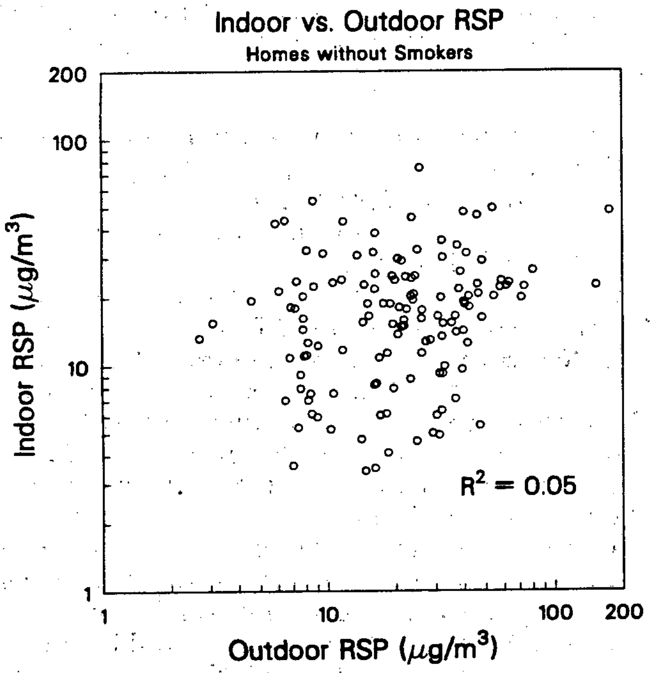

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Figure 27 Comparison of outdoor RSP in homes without occupants who smoke with outdoor RSP levels. The lack of relationship suggests that houses provide an important buffer against this outdoor air pollution.

ventilation measurements, strict comparisons between the three periods are not valid unless corrections for changes in environmental conditions are made. Indoor and outdoor RSP concentrations are summarized for control and study homes for both pre- and post-weatherization periods in Table 15. Geometric mean indoor concentrations ranged from 24.2 $\mu g/m^3$ to 30.5 $\mu g/m^3$ for the study homes and from 10.0 to 16.7 $\mu g/m^3$ for the control homes. Because indoor RSP levels are often lower than outside and are sensitive to indoor sources, comparison of pre- and post-weatherization data is not valid. Any attempt to interpret or model the behavior of indoor RSP under the influence of weatherization house-tightening would require information on indoor source terms and use factors -- data that were not collected in this study. Generally those homes with higher concentrations had occupants who smoked. Appendix H examines the effects of smoking and indoor combustion sources (fireplaces, woodstoves, kerosene heaters, etc.) on indoor RSP levels. A sizable number of indoor (21) and outdoor (14) measurements exceeded the National Ambient Air Quality Standards (NAAQS) for particles having diameters less than 10 μm (PM_{10} - $50 \mu g/m^3$). Outdoor concentrations were often elevated during periods of cold weather accompanied by a temperature inversion. Figure 27 relates elevated indoor levels in homes without smokers to outdoor levels. For 131 comparisons, the R^2 is less than 0.05, reconfirming work by others that suggests that the penetration coefficient for transport of these particles through the house is small.

Radon.

As seen in the screening survey, indoor radon levels were highest in the Spokane/Coeur d'Alene region with a mean concentration of 7.2 pCi/L versus Vancouver area homes averaging 2.2 pCi/L during the pre-weatherization period. More specifically, those homes in the Spokane River Valley/Rathdrum Prairie of eastern Washington and northern Idaho had elevated indoor levels primarily as a result of the high air permeability of the gravelly, glacial outwash soils. Concentrations in the Vancouver homes in this phase of the study are similar to those of region-wide surveys mentioned earlier. The baseline period radon data is presented as a histogram in Figure 28. The tail of the distribution is mostly filled with homes from the Spokane/Coeur d'Alene area.

We must be careful not to interpret the lower post-weatherization radon levels in Table 14 as an indication that weatherization necessarily reduces indoor concentrations. As already mentioned, these data were collected under different conditions. This may have had an impact on the entry rate of radon-laden soil gas driven into the house by indoor-outdoor pressure differences that are, in part, due to indoor-outdoor temperature differences. For 39 homes, the mean baseline concentration fell 43% from 4.2 pCi/L (GSD 3.6) to 2.4 pCi/L (GSD 3.7). Using a one-tailed t-test for paired comparisons, this difference is significant at the $0.1<P<0.2$ level. For the same periods, PFT-measured ventilation changed less than 5% (Table 12). All house substructure types appear to exhibit reduced radon levels after weatherization, although crawlspace homes have the largest reduction (approximately 50%). See Table 16. Mean ventilation rates do not always increase sufficiently to account for the reduction alone. However, a primary entry mechanism for radon, indoor-outdoor temperature difference, is diminished for many of the post-weatherization periods. It may be sufficient to cause the observed reductions in indoor radon. For homes with crawlspaces, the reduction is more likely due to the weatherization program that provides more openings in the crawlspace for additional ventilation for moisture control. These openings to the outside would: 1) decouple the house depressurization from the soil, and 2) reduce the radon concentration in the crawlspace air that is subsequently drawn into the house with infiltrating air (Nazaroff and Doyle, 1985a).

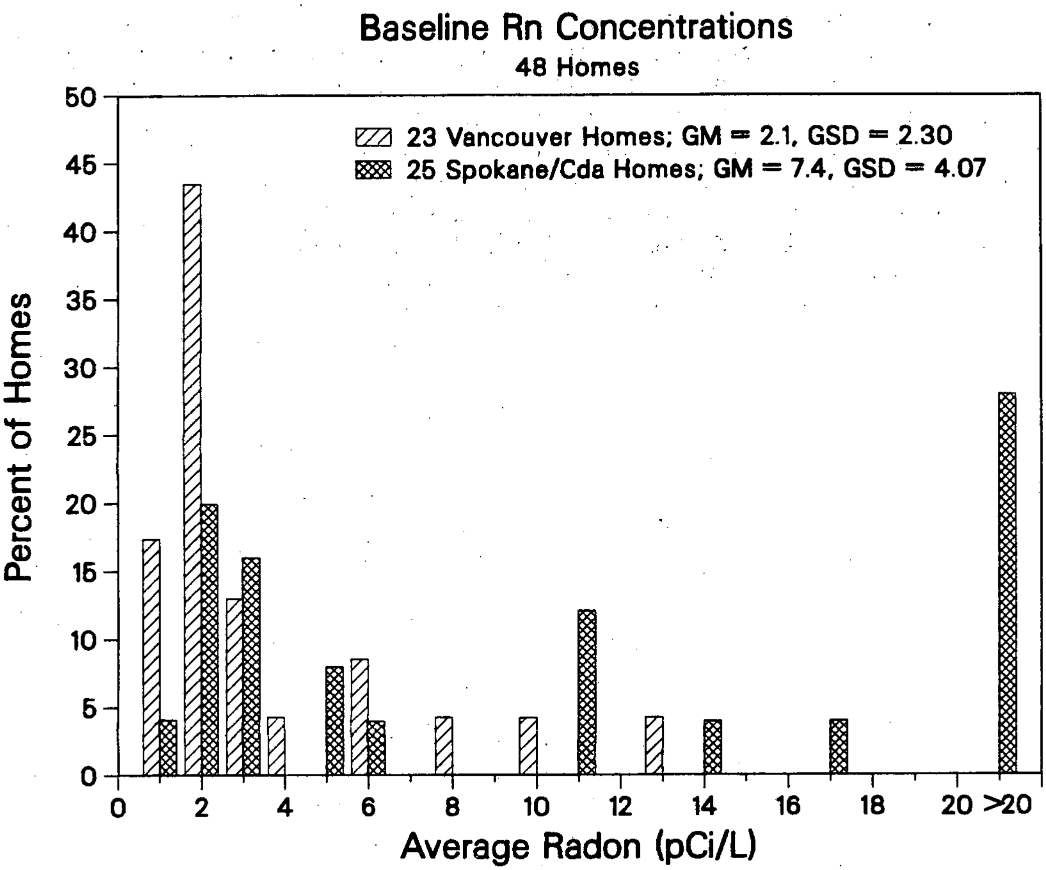

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Figure 28 Distribution of baseline radon concentrations for the 48 homes show the regional differences between Spokane/Coeur d'Alene and Vancouver.

Pollutant distribution within houses.

Data from pollutant measurements at more than one location in each house are grouped by type of location in Table 17. Pre- and post-weatherization data are uncorrected for differences in environmental conditions for each of the three pollutants. The means are ordered by increasing concentrations at a location for the baseline period. Interestingly, the order is almost always preserved in the post-weatherization period with the exception of the living room and hall locations for HCHO and NO_2. This suggests that differences between locations are real and that weatherization did not affect these pollutant distributions. The order of increasing water vapor concentrations is not reflected in an increase in HCHO. However, the differences in water vapor concentration by location are small. There is no general physical explanation for these distributions, although at least two sources (bathrooms and kitchen are sources for water vapor and often have greater amounts of particle board for HCHO) or various removal devices (fans and windows etc.) could result in the systematic difference. The results do indicate that pollutant mixing in these houses is good. This observation is consistent with results of Traynor *et al.*, (1982).

TABLE 16. PHASE 2 WEATHERIZATION SENSITIVITY
RADON CONCENTRATIONS BY SUBSTRUCTURE TYPE
UNCORRECTED FOR ENVIRONMENTAL CONDITIONS
COMPARED WITH VENTILATION RATES AND INDOOR-OUTDOOR TEMPERATURE DIFFERENCE

	BASEMENT		CRAWLSPACE		COMBINATION	
	BASELINE	POST WXTN	BASELINE	POST WXTN	BASELINE	POST WXTN
RADON (pCi/L)						
NO. HOMES	10	10	10	10	16	16
GM	9.62	7.05	1.91	0.88	3.63	2.06
GSD	4.34	6.09	2.86	1.98	2.88	2.15
PFT-MEASURED VENT. (h^{-1})						
NO. HOMES	10	10	10	10	16	16
GM	0.31	0.42	0.38	0.37	0.44	0.42
GSD	2.25	1.73	2.06	1.89	1.96	1.89
INDOOR-OUTDOOR ΔT (°C)						
NO. HOMES	9	9	10	10	15	15
AM	23.4	23.2	20.6	16.1	21.8	15.5
GM	22.9	22	20.2	15.4	21.3	14.8
ASD	4.6	7.7	4.3	5	4.7	4.9
GSD	1.2	1.4	1.2	1.4	1.3	1.4

TABLE 17. PHASE 2 - WEATHERIZATION SENSITIVITY INDOOR POLLUTANT DISTRIBUTION

40 Study Homes

Pollutant/ Sample Location	Baseline No. Sample Locations	Baseline Mean	Baseline Standard Deviation	Post Weatherization No. Sample Locations	Post Weatherization Mean	Post Weatherization Standard Deviation
HCHO (ppb) Geometric						
Kitchen	(4)	19.9	1.5	(4)	20.0	1.4
Other	(64)	26.8	1.8	(65)	28.6	1.8
Living Room	(35)	28.6	1.8	(33)	30.5	1.7
Hall	(25)	31.3	1.5	(22)	30.1	1.5
H_2O (g/kg) Arithmetic						
Kitchen	(4)	4.77	0.56	(4)	5.57	0.52
Hall	(24)	5.50	0.97	(22)	5.91	1.03
Other	(65)	5.68	1.00	(65)	6.15	1.37
Living Room	(33)	5.81	0.83	(33)	6.27	1.09
NO_2 (ppb) Geometric						
Other	(63)	3.4	2.2	(65)	3.0	1.9
Hall	(24)	3.7	1.8	(22)	3.4	1.7
Living Room	(34)	3.9	2.0	(33)	3.1	1.7
Kitchen	(4)	6.2	1.5	(4)	4.3	2.0

IV. MODELING AND DISCUSSION

A. CONTROL HOUSE SEASONAL CHANGES

The control houses in this project were monitored throughout the weatherization phase to give information about changes in pollutant concentrations that are not the result of the weatherization. These non-weatherization changes can occur as the result of two different mechanisms. Changes in environmental conditions (primarily wind speed and outdoor temperature) can cause changes in the infiltration rates and possibly pollutant source strengths in the houses. Since infiltration is the dominant mode of ventilation for residences, these changes in infiltration may cause changes in pollutant concentrations that are unrelated to weatherization. For some pollutants, the changes due to environmental effects are moderately well-understood (the dependence of formaldehyde emission rates on temperature and relative humidity), while in other cases (e.g., radon), they are not.

A simple tracking of changes in control home air quality parameters is shown in Figure 29. Here the data from the monthly measurement periods is normalized to the initial period for each control home. The change for each parameter is averaged from all of the control homes and plotted through April. Especially interesting is the observation that the ventilation rate predicted using the LBL model tracks well with the PFT-measured rate when the data are aggregated in this manner. This was not seen in the earlier comparisons. Figure 29c shows the dependence of indoor water vapor levels on outdoor levels that was also noted in Figure 22. While this procedure does indicate the relative change in HCHO, H_2O, radon, and building tightness as caused by a number of conditions (some mentioned above; others include occupant activities), it is only for a 10-day period each month. Homes undergoing weatherization were not always monitored concurrently with the control homes, so that changes in the control homes are not necessarily applicable to the study homes. Because of the limitations in this type of analysis, another approach was followed.

B. PARAMETER DEPENDENCE

All further analysis required pollutants whose indoor concentrations would most likely be sensitive to the effects of weatherization; that those pollutants be at measureable concentrations; and that sufficient data points were available. Water vapor, HCHO, and radon satisfied these criteria.

If weatherization were to result in modified ventilation rates, then, a first order approximation derived from the following steady-state mass balance model would indicate that pollutant levels should change.

$$C_i = \frac{S/V}{R} + C_o \qquad [2]$$

where C_i is the average indoor air pollutant concentration, S is the generation rate of the indoor pollutant, V is the building volume, C_0 is the outdoor pollutant concentration, and R is a removal rate assumed to be dominated by ventilation rate, λ. Others have shown that in typical residences, the air infiltration is related to the wind speed, v, and the indoor-outdoor temperature difference, ΔT, by an expression of the form

$$\lambda = B\,(D\Delta T + Gv^2)^\eta \qquad [3]$$

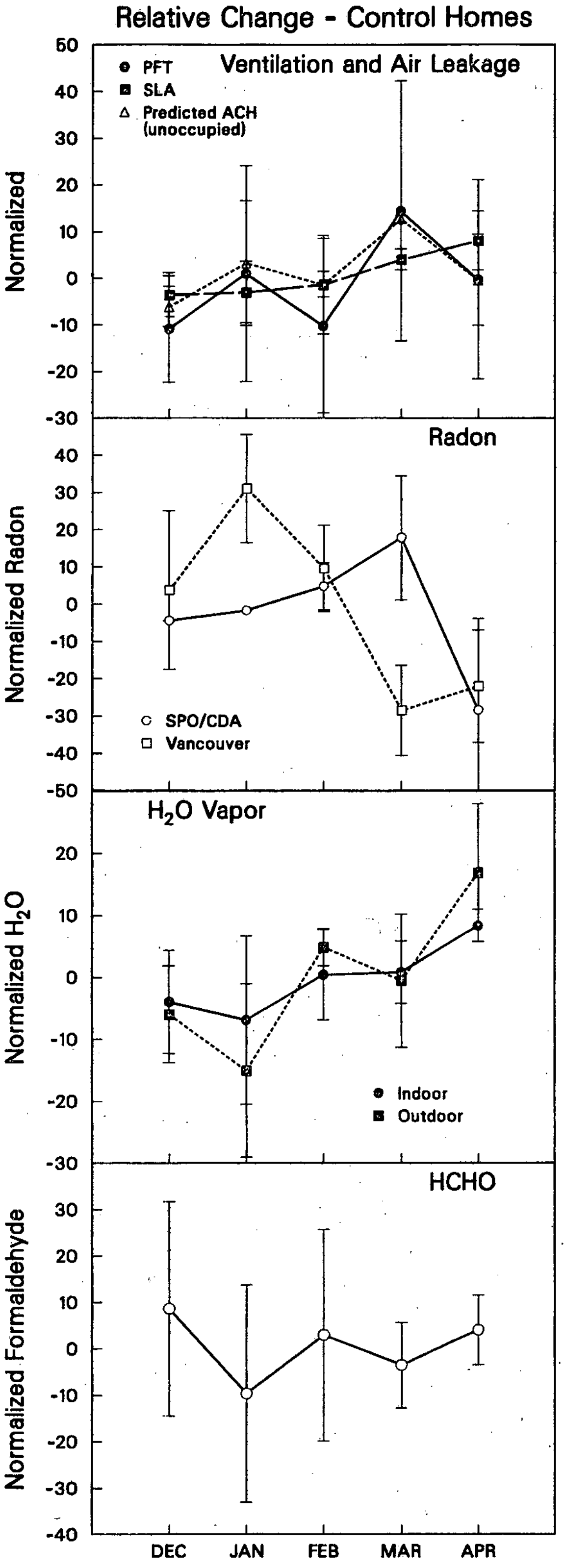

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Figure 29 Seasonal changes in HCHO, H_2O, radon, SLA, and measured ventilation for the control homes. Data from the monthly measurement periods are normalized to the initial period for each control, then averaged from all of the control homes.

where B, D, and G are constants that depend on the structure and η is a number that typically lies between 0.5 and 0.65 (Grimsrud *et al.*, 1986; Sherman and Grimsrud, 1980). Therefore, to indirectly address the issue of changes in pollutant concentration with weatherization, normalized pollutant concentrations were compared with normalized PFT-ventilation measurements and specific leakage area measurements (SLA).

The relative change in the parameters were computed by

$$C_{norm} = \frac{(C_i - C_o)_{post}}{(C_i - C_o)_{initial}} \, , \qquad [4]$$

$$\lambda_{norm} = \frac{\lambda_{initial}}{\lambda_{post}} \, , \text{ and} \qquad [5]$$

$$L_{norm} = \frac{L_{initial}}{L_{post}} \, . \qquad [6]$$

L is the specific leakage area, and the subscripts, *initial* and *post*, indicate the initial test period and any test period after the initial period, respectively. All homes with data available for more than one measurement period, including control homes, were used. This analysis was not looking for changes due only to weatherization, but to changes in pollutant levels due to any change in ventilation rate. To more easily visualize the dependence of changing pollutant levels on changing ventilation rates, the normalized concentration, ventilation, λ_{norm}, and specific leakage area, L_{norm} (equations 5 and 9 are defined as the initial over the post measurement). Thus, when plotted against normalized pollutant concentrations, the idealized result would be a straight 45° line. Many comparisons were made and Figures 30 - 33 are examples of the results. The fit to the expected line is usually poor. We would expect to find changes in pollutants where changes in SLA or ventilation rates were large. Figure 30 displays data where H_2O vapor concentration is plotted versus ventilation rate when the ventilations rates showed a change of more than 20% over the initial period. The data are uncorrelated. Similarly, in Figure 31a,b, HCHO is compared with changes in SLA and ventilation rate, both with changes greater than 20% from the initial period. Only for SLA is there any correlation ($R^2 = 0.22$), but even this is weak.

Because the factors that affect ventilation rates also affect radon entry rates from the soil, it is not surprising that there is also no correlation of radon with ventilation for the 42 homes in Figure 32a. Even in Figure 32b, where only those homes with initial radon levels greater than 3 pCi/L and with changes in ventilation greater than 20% are compared, correlation is very poor. Some improvement is achieved by examining the radon and ventilation changes for those houses with basement and/or slab substructures and without crawlspaces (Figure 33a,b). Only in these homes do the changes show a moderate correlation, having an R^2 up to 0.20 for those homes with large changes in ventilation rates (Figure 33b). Homes with these substructures may be less exposed to the influence of wind and changing air leakage area of the substructure (and radon entry rate) due to weatherization, as is the case for homes with crawlspaces.

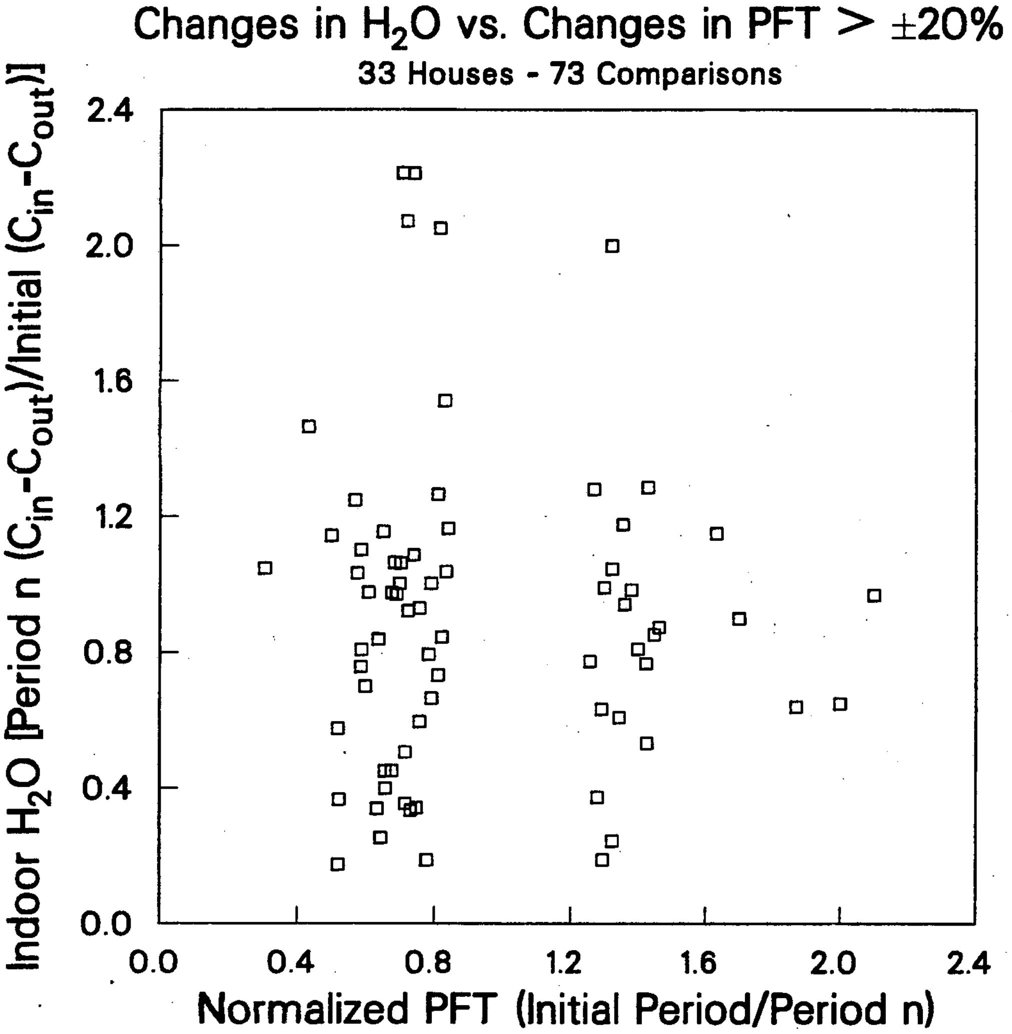

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Figure 30 The relative change in H_2O vapor concentrations and PFT-measured ventilation rates (greater than 20% different from the initial period) shows no correlation. Other factors are causing the variation in indoor concentrations.

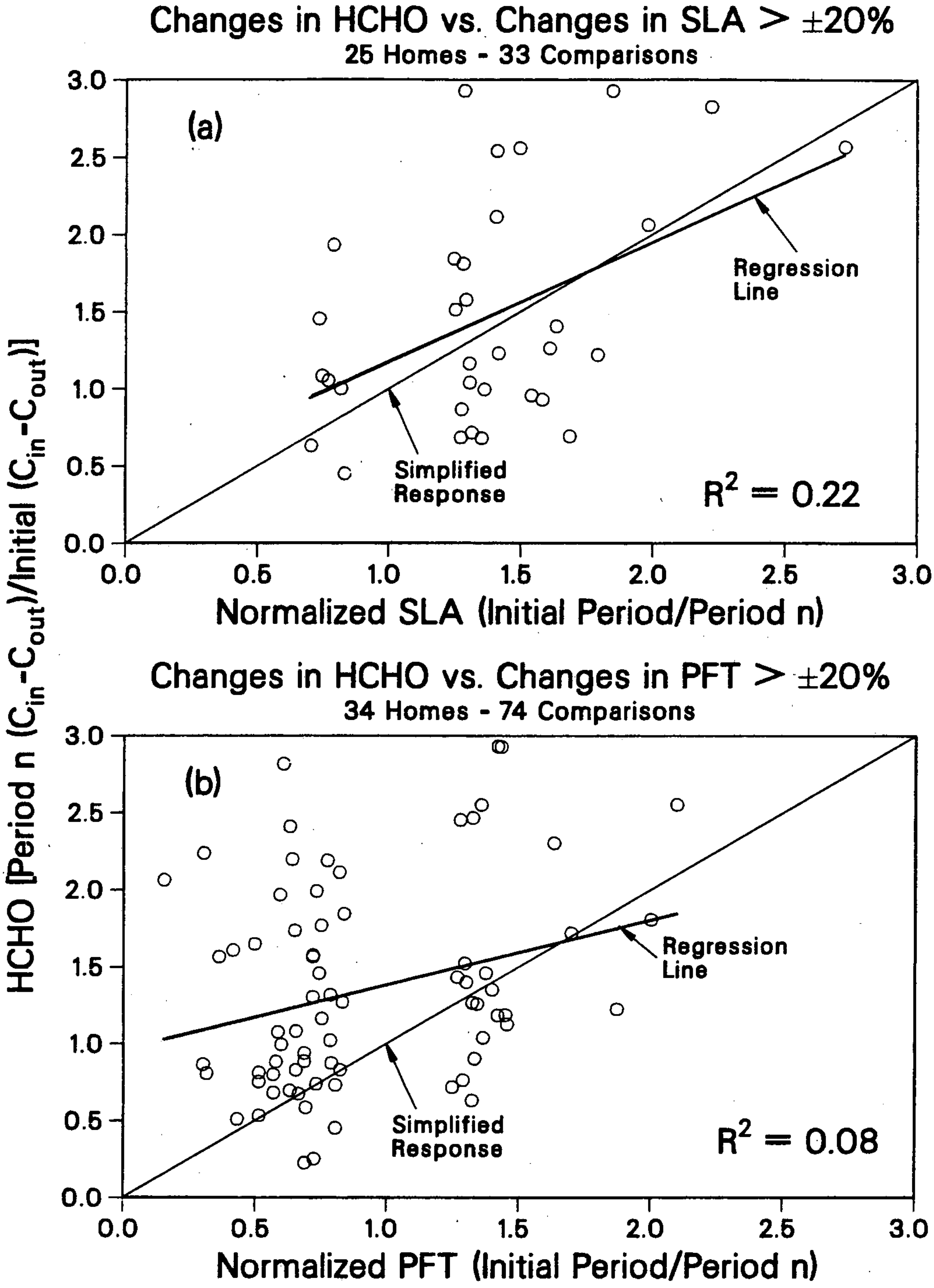

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Figure 31 a,b Changes in HCHO are plotted against changes in SLA and ventilation rates greater than 20% from the initial period. There may be a weak correlation to SLA, but there is none for ventilation rates.

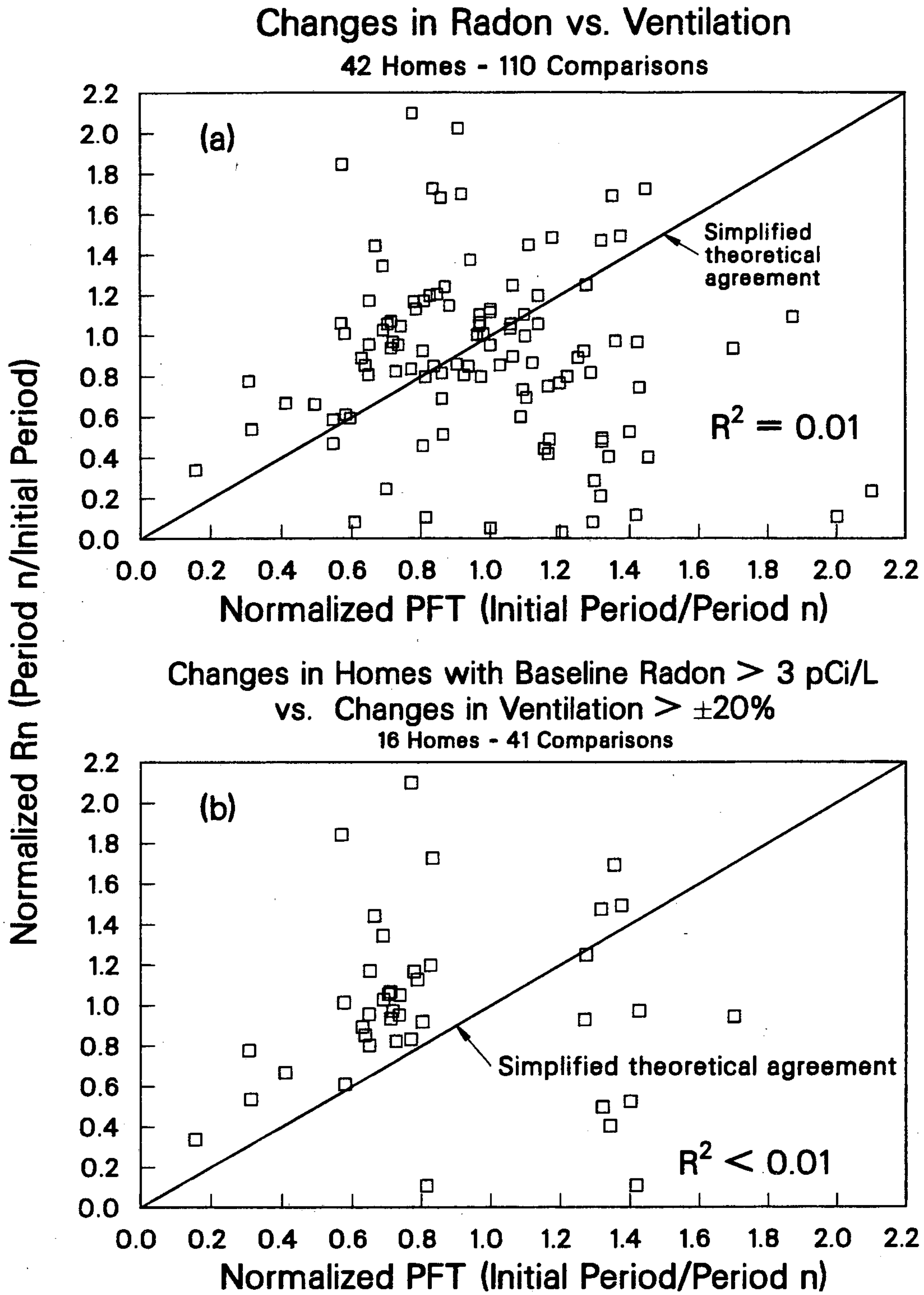

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Figure 32 a,b Changes in indoor radon and ventilation are compared and show little or no correlation. Figure (b) includes only those homes with initial radon levels greater than 3 pCi/L and changes in ventilation greater than 20%.

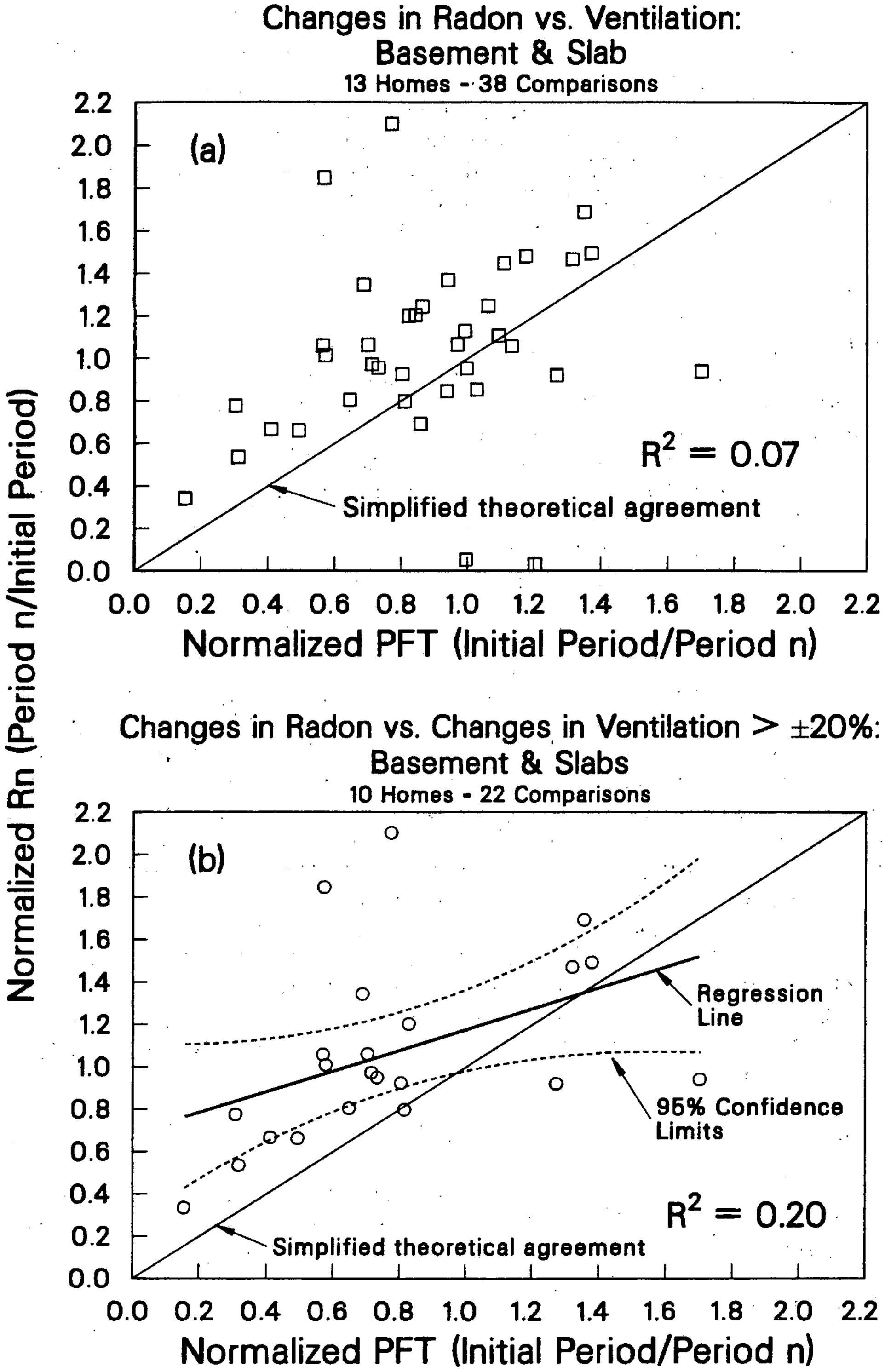

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Figure 33 a,b By selecting homes with basement and/or slab substructures, the correlation between indoor radon and ventilation rates is improved, particularly where changes in ventilation were large. These substructures may be more immune to the influence of factors such as wind and changing leakage area of the substructure due to weatherization.

For H_2O vapor, formaldehyde, and radon, there appear to be influences other than ventilation that dominate the indoor concentrations. These could include variable indoor sources (H_2O vapor); occupant effects (H_2O vapor); and more complex dependence on other factors such as structure storage effects (H_2O vapor), indoor humidity and temperature (HCHO), wind, soil characteristics, barometric pressure, furnace operation, and ΔT (radon). This makes the study of the relationship between indoor pollutant levels and house-tightening weatherization very difficult.

C. MODELING

The final strategy in analyzing the data is an attempt to model the changes in concentrations seen in those homes using the measured environmental parameters. The data from the control homes and from homes participating in the follow-up study are used in this analysis. Data represent seven to ten-day averages except where noted. Values for the parameters from these models are then used to model the concentrations in all homes. In turn, these models are used to calculate post-weatherization concentrations for a set of standard house and environmental conditions that would account for these non-weatherization effects. See Appendix I for a discussion of the statistical techniques used in interpreting results of the modeling.

Radon

Much of the work in this section derives from research in progress by one of the authors (Revzan *et al.*, 1987) on data from intensive studies of indoor radon in New Jersey homes (Sextro *et al.*, 1987), and Spokane/Coeur d'Alene homes (Turk *et al.*, 1987a). It is based, in part, on recent model development by Arvela and Winqvist (1986) and is exploratory in nature and should be considered preliminary. Because of differences in house construction, distribution of air leakage area, soil types, microclimatological conditions, and occupant usage, it is not possible to derive a radon model that is applicable to all houses for all test periods. While not all of these parameters were measured in this study, an expanded derivation is described for reference, and is followed by a simplified model supported by data from this study. The total radon source, S, is assumed to be dominated by the pressure-driven flow of soil gas into the structure (Nazaroff *et al.*, 1985; 1986). Diffusion is assumed to be negligible. From Darcy's law, the flow of soil gas is proportional to ΔP (DSMA, 1985) and the source can be approximated by

$$S = F \, \Delta P \, C_s \qquad [7]$$

where: F is a constant determined by house and soil properties, C_s is the soil gas radon concentration adjacent to the house substructure entry points, and ΔP is the pressure difference across the substructure shell and soil at the entry points.

Equation 2 may be modified to include the flows of air between zones in a house.

$$C_b = \frac{f_{sb}C_s + f_f C_l}{f_{ob}} \qquad [8]$$

where C_b is the basement radon concentration, C_l is the first floor living area concentration, C_s is the soil gas concentration, C_o is assumed to be zero, f_{sb} is the soil to basement flow, f_{ob} is the outside air to basement flow, and f_f is the flow to the basement from the first floor due to forced-air furnace operation. This term is present only when the furnace is in operation.

The concentration in the living area is described by:

$$C_l = \frac{f_{bl} C_b}{f_{lo} + f_f} \tag{9}$$

where f_{bl} is the basement to living area flow. Solving for C_l, then gives

$$C_l = \frac{f_{bl}(f_{sb} C_s)}{f_{ob} f_{lo} + (f_{ob} - f_{bl}) f_f} \tag{10}$$

To simplify this model, since most of these flows are not known, we further assume that the basement and first floor living areas act as one zone.

Soil gas radon can be approximated by

$$C_s \approx 1 - \exp\left[\frac{-\beta}{\Delta P}\right], \tag{11}$$

where β is ≥ 0 and depends on soil permeability and house configuration (Revzan, *et al.* 1987). Incorporating the simplifications and equations 2, 3, 7, and 11:

$$C_i = \frac{F \, \Delta P (1 - \exp\left[\frac{-\beta}{\Delta P}\right])}{BV \, (D \Delta T + G v^2)^{\eta}} + C_o \, . \tag{12}$$

While v affects both ventilation and the source terms to varying degrees, it is neglected here in an effort to further simplify the model.

The indoor-outdoor pressure difference (ΔP) is thus dominated by the stack effect, and, hence, is proportional to the indoor-outdoor temperature difference (ΔT). (Strictly speaking, we should be including indoor basement and/or crawlspace temperatures and outdoor soil temperatures, as appropriate, but the data are not generally available in this study. What should be done in the case of houses with both a basement *and* a crawlspace is unclear.)

With the assumptions and simplifications noted above, the natural ventilation air exchange rate of a house will be proportional to ΔT^{η}.

$$C_i = \frac{F \, \Delta T (1 - \exp\left[\frac{-\beta}{\Delta T}\right])}{BVD \, \Delta T^{\eta}} \tag{13}$$

Simplifying,

$$C_i = F' \Delta T^{\alpha} (1 - \exp(-\beta/\Delta T)), \qquad [14]$$

where $\alpha = 1 - \eta$ which typically is expected to lie between 0.35 and 0.5, and F' is now a lumped constant including B, D, and V.

Based on the subsequent study of radon mitigation in Spokane/Coeur d'Alene homes, the soil gas term is assumed to be constant. We further assume that the three parameters are independent of time, so that the radon concentration for a single house is

$$C_i = F'\Delta T^{\alpha} \qquad [15]$$

The simplified model is evaluated on one Spokane home participating in the radon mitigation study. Results in Figure 34 show that the model approximates continuous living space radon concentrations in this house (but with an unusually high α of 1.07). However, it does not perform as satisfactorily in other houses.

A similar, more empirical model, using PFT-measured ventilation rates in place of ΔT in equation 15 can be proposed,

$$C_i = E\lambda^{\phi} \qquad [16]$$

where E is a constant, and ϕ is a number expected to lie between -1.0 and 0.0, depending on the nature of the relationship between the soil gas concentration and the soil-to-basement flow rate. In this model, changes in ventilation rates most directly affect indoor radon levels by removal of the indoor air. Changes in ventilation will only indirectly indicate changes in the entry rate of radon from the soil.

Presumably, either equation 15 or 16 should apply to all cases since the measured ventilation rate and the temperature difference are expected to be correlated. However, as seen earlier, correlation between the two is poor, calling into question the validity of either technique to represent actual ventilation rates. Tables 18 and 19 summarize the results of fitting five or more measured data to the two models. The fitting procedure minimized the sum of the squares of the residuals. House ECD026C supports the ΔT model (equation 15 and Table 18), house EVA510C supports the PFT ventilation model (equation 16 and Table 19), while house ECD027C lends support to both. The ventilation model works best in the Vancouver homes that have generally low indoor radon concentrations (EVA604 < 12 pCi/L, EVA510C < 2 pCi/L, EVA505C < 2 pCi/L) compared with the Spokane/Coeur d'Alene area homes. This suggests that the source term for these Vancouver houses is smaller and less dependent on the driving force produced by larger ΔT than in the Spokane/Coeur d'Alene houses, and that removal by ventilation is more important.

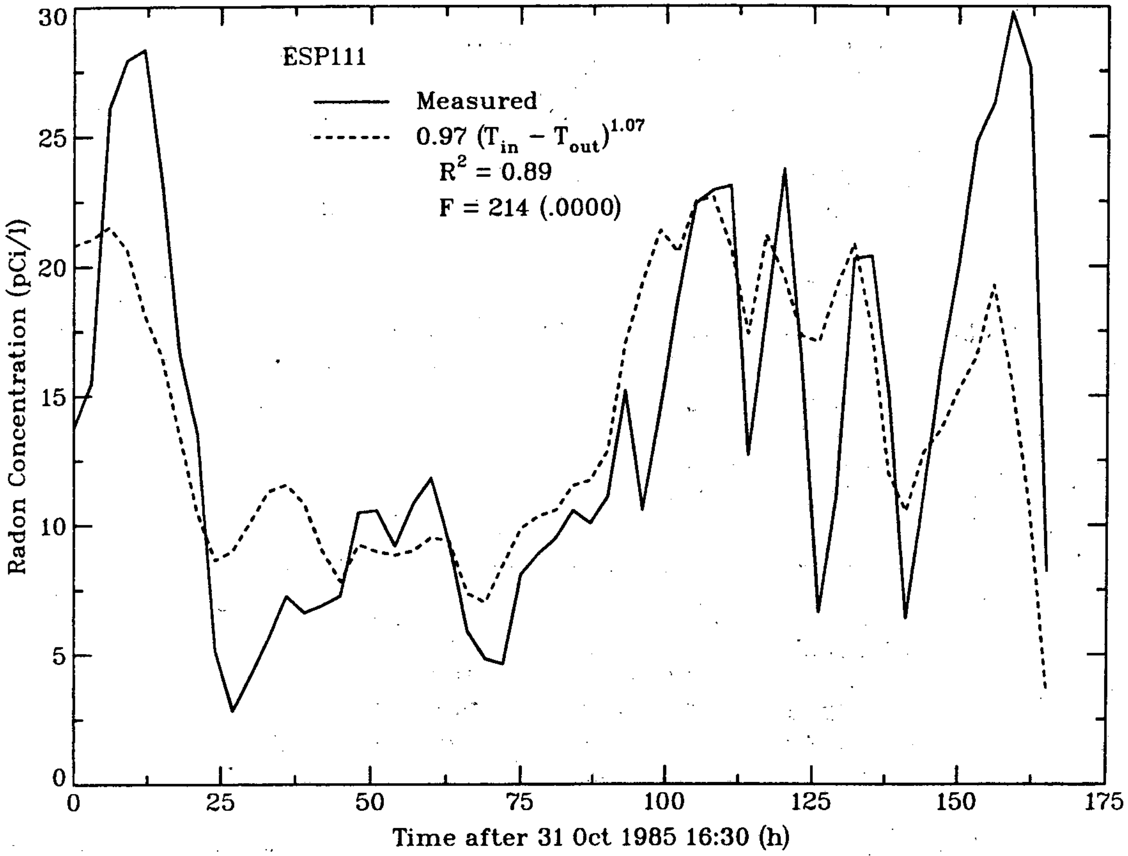

Figure 34 Model and results for Spokane area home participating in the subsequent radon mitigation study using equation 15. Model does not perform this satisfactorily in other houses.

Table 18. Fitting Data Values to ΔT Model, Equation 15

House Code	Number Periods	A	α	R^2	F*
ECD026C	17	4.4	0.42	0.41	5
ECD027C	7	21.3	0.29	0.60	4
ESP108	17	42.5	-0.31	0.15	1
EVA505C	5	0.2	0.68	0.20	0
EVA510C	5	0.2	0.61	0.20	0
EVA604	6	6.9	0.11	0.02	0

Table 19. Fitting Data Values to PFT Ventilation Rate Model, Equation 16

House Code	Number Periods	E	ϕ	R^2	F
ECD026C	17	16.9	0.07	0.01	0
ECD027C	7	42.5	0.66	0.50	3
ESP108	17	9.6	-0.45	0.29	3
EVA505C	5	17.5	2.38	0.55	2
EVA510C	5	0.3	-1.09	0.95	29
EVA604	6	3.8	-0.49	0.42	1

Since equation 15 is a more generalizable model, it can be used to predict post-weatherization radon levels from baseline levels:

$$C_{PWX} = \left[\frac{\Delta T_{PWX}}{\Delta T_{BSL}} \right]^{0.5} C_{BSL} , \qquad [17]$$

where the subscripts *BSL* and *PWX* are baseline and post-weatherization period measurements. The exponent, α, is chosen to be 0.5 on the basis of worst case assumptions of ventilation dependent on $(\Delta T)^{0.5}$ and soil gas entry on $(\Delta T)^{1.0}$ and results from Table 18. A plot of measured and expected values for 38 of the study

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*Note that values of the Fisher statistic (F) that are significant at >0.999 are denoted by one asterisk, and >0.9999 are denoted by two asterisks. See Appendix I for a description of the statistical tests used, including R^2.

houses (44 comparisons) is given in Figure 35, which also shows the substructure type of the house. It is important to note that this model does not directly predict the effects of weatherization by accounting for changes in the distribution of air leakage area. Instead, it predicts post-weatherization concentrations indirectly by assuming that radon entry and ventilation rates are dependent only upon changes in ΔT. Obviously, a more accurate and sophisticated model would incorporate those leakage area changes, but measurements to quantify those changes are currently very difficult or impossible.

The predictive ability of the model is satisfactory for most basement homes, with the exception of house EVA660. The pre-weatherization baseline period (measured) mean radon concentration was 12.5 pCi/L, and all periods after that were less than 1.0 pCi/L. No physical change due to the wall insulation (when the drop is noted) can be established. Occupant diaries also do not indicate any significant changes. Since the screening survey results (4.23 pCi/L) substantiate the baseline period measurement, instrument malfunction can be ruled out. Therefore, we presume that some structural change occurred in the building between the baseline and wall insulation period not related to the weatherization. The other homes that do not fall on the line of agreement have substructures with crawlspaces. Not surprisingly, the model does not account for the structural change caused by adding ventilation openings to crawlspaces as part of weatherization. These openings tend to decouple the occupied spaces from the source -- the soil -- in two ways. First, the depressurization at the soil surface of the crawlspace is reduced, thereby diminishing radon entry into the crawlspace. Secondly, the ventilation rate of the crawlspace is increased, which reduces the amount of radon in the crawlspace air that can be drawn into the house through the house/crawlspace walls and floors along with infiltrating air. Figure 36 is an example of a house (ECD150) where indoor radon dropped dramatically as a result of crawlspace ventilation being added during weatherization. The post-weatherization measurement periods (as shown in the figure) aren't of long enough duration to provide conclusive data, but do indicate the trend. In those homes having both basements and crawlspaces, crawlspace ventilation may control only the radon originating in the crawlspace, while the basement continues to be an entry location (Turk *et al.*, 1987a).

Equation 17 may also be used to normalize data to standard temperature conditions so that there is a basis for comparison between the different measurement periods.

$$C_{norm} = \left[\frac{\Delta T_{norm}}{\Delta T_{BSL,PWX}} \right]^{0.5} C_{BSL,PWX} \qquad [18]$$

The following Tables 20-22 provide the geometric mean and standard deviation of the baseline and post-weatherization values normalized to a 20 °C ΔT. The normalization routine is applied separately to the different substructure types.

The probability, P, that the post-weatherization means are *not* less than (or greater than, depending on which pair of means are compared) the baseline means are indicated in the right column of Tables 20-22 and were derived from a one-tailed t-test of the difference between two means with equal sample sizes.

The radon levels after weatherization are always lower than the baseline conditions. Only those reductions of indoor radon in the crawlspace homes are significant. Table 21 shows that the before and after differences are greater in those homes with baseline levels greater than or equal to 3 pCi/L. By restricting the comparison to only those higher level homes, we hoped to improve the discrimination by reducing measurement

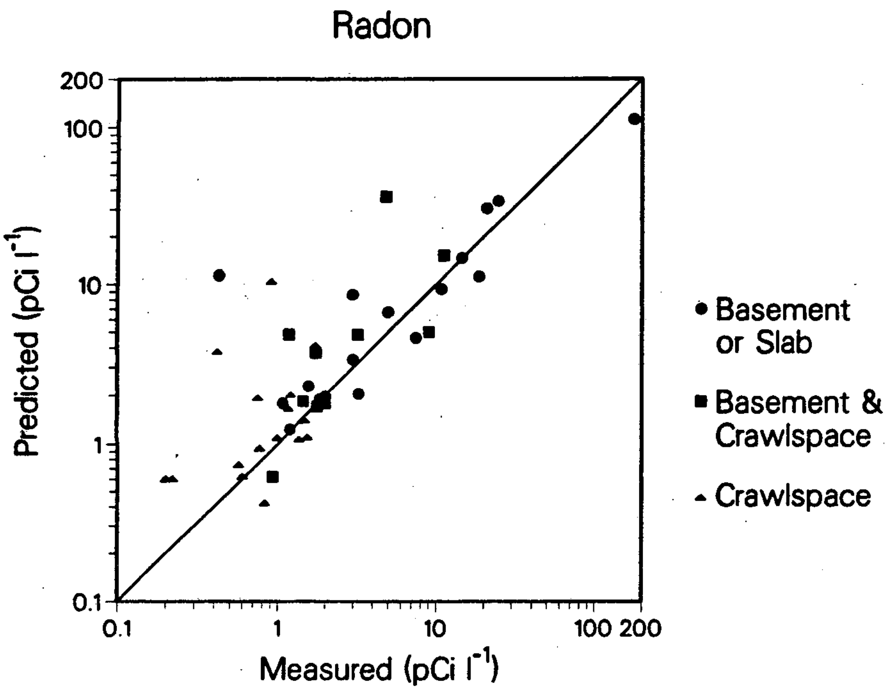

Figure 35 Model-predicted radon levels following weatherization compared with measured levels for 44 periods (38 homes). Agreement is satisfactory for homes with basements/slabs. The model overpredicts for homes with crawlspaces, since the additional ventilation in the crawlspaces has changed the operating characteristics of the house.

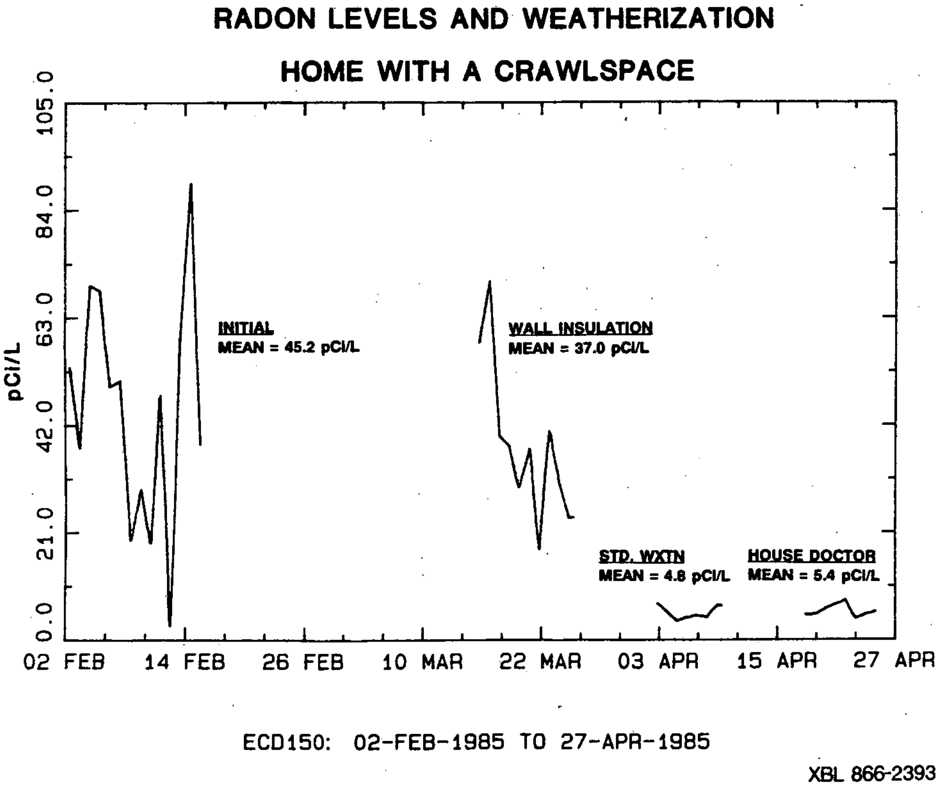

Figure 36 Continuous radon measurement in the occupied space of a home with a crawlspace (ECD150) before and after BPA's standard weatherization. The weatherization retrofit included additional ventilation area in the crawlspace that reduced crawlspace radon levels and decoupled the house from the soil. Further house doctor weatherization did not result in any appreciable change in radon levels.

Table 20. Modeled Pre- and Post-Weatherization Radon Concentrations -- All Homes Corrected to Standard Temperature Conditions of 20 °C ΔT

Sub-structure type	Number Periods	Baseline GM (pCi/L)	Baseline GSD	Post-Weatherization GM (pCi/L)	Post-Weatherization GSD	Probability
Basement, Slab	17	6.89	3.30	5.37	4.09	0.45>P>0.25
Basement + crawl space	10	4.71	2.98	3.19	2.22	0.2>P>0.1
Crawl space	17	1.61	2.19	0.92	1.85	0.025>P>0.01
All	44	3.61	3.33	2.42	3.61	0.1>P>0.05

uncertainty. The results are little different from those of Table 20, which includes all homes. By looking at only those homes whose SLA was reduced by more than 20%, we hoped to exaggerate any effect due to increasing house tightness. Again, results are the same as the two previous tables, except that baseline and post-weatherization radon levels are almost certainly equal in the basement and slab substructure homes.

Explanations for reductions in radon levels after weatherization in those homes with crawlspaces are straightforward. For homes with slabs, basements, or combination substructures, the reasons are more obscure. First, the model is simple; the uncertainties in predicted concentrations may be large. Consequently, small changes in

Table 21. Modeled Pre- and Post-Weatherization Radon Concentrations -- Baseline Concentrations ≥3 pCi/L Corrected to Standard Temperature Conditions of 20 °C ΔT

Sub-structure type	Number Periods	Baseline GM (pCi/L)	Baseline GSD	Post-Weatherization GM (pCi/L)	Post-Weatherization GSD	Probability
Basement, Slab	11	13.30	2.58	9.40	4.32	0.45>P>0.25
Basement + crawl space	6	8.72	2.52	4.29	2.48	0.2>P>0.1
Crawl space	3	6.38	1.31	0.98	2.28	0.05>P>0.025
All	20	10.50	2.44	5.29	4.18	0.05>P>0.025

indoor concentrations (as one would expect with a small change in SLA) would be obscured. Second, the act of air leakage tightening during weatherization may change the leakage distribution such that the radon entry rate is reduced, actually resulting in the lower levels, as predicted by these models. Unfortunately, except for the crawlspace homes, this analysis is unable to conclusively determine that weatherization has either a positive or negative impact on indoor radon levels. It is clear, however, that weatherization does not dramatically increase radon concentrations, as had been previously feared.

Several approaches could help to improve on this study: 1) a study of a larger number of homes with more before and after measurements made during similar environmental conditions would improve the statistical resolving power; 2) a small study, such as this one, that collected data on more variables including soil moisture, soil gas radon concentrations, real-time, multi-zone ventilation rates, and house shell pressure differentials that we now believe are important in understanding and modeling radon entry and removal; 3) revisiting the continuous data collected during this study to create a quasi-physical, empirical, house-specific model for the radon levels during baseline in each of the 48 houses. Since these models would be based on 30- or 60-minute data intervals, their predictive capability should be improved for the relatively short seven- to ten-day post-weatherization period. And 4) a laboratory-based study that uses controlled experiments to develop a generalized source model incorporating leakage area distributions. This could be used by a generalized indoor air quality model to predict the impact of weatherization on indoor radon concentrations (or other indoor air quality variables).

Table 22. Modeled Pre- and Post-Weatherization Radon Concentrations --
SLA Changed $\geq$ -20%
Corrected to Standard Temperature Conditions of 20 °C ΔT

Sub-structure type	Number Periods	Baseline GM (pCi/L)	Baseline GSD	Post-Weatherization GM (pCi/L)	Post-Weatherization GSD	Probability
Basement, Slab	6	10.91	4.61	11.04	5.49	P>0.9
Basement + crawl space	5	3.72	4.09	2.41	1.64	0.45>P>0.25
Crawl space	5	2.31	3.32	0.89	1.40	0.10>P>0.05
All	16	4.80	4.35	3.12	4.48	0.25>P>0.2
				(Post-house doctor)		
House doctor	5	10.26	2.18	3.05	2.53	0.10>P>0.05

Water Vapor

Sophisticated models of indoor air water vapor and humidity ratios and indoor building materials humidity ratios have been developed and explored by Tsuchiya (1980), by Kusuda (1983), and in a simpler model for attics by Cleary (1985). However, many of the parameters required for those models were not measured in this study. The models are important to investigate because they suggest the important parameters that influence water vapor concentrations. These include ventilation rate, outdoor water vapor concentration, and interior surface material temperatures.

We consider, following Cleary, indoor water vapor concentrations to be governed by the following equation:

$$C_i = \frac{\dfrac{p_i \exp(p_2 T_i)}{V\lambda} + C_{out}}{1 + \dfrac{p_3}{V\lambda}} \qquad [19]$$

where C_i is the indoor concentration (gkg^{-1}), T_i is the average indoor air temperature and approximates surface material temperatures (°C), V is volume (m^3), λ is PFT-measured air exchange rate (h^{-1}) and p_1, p_2, and p_3 are parameters, with units m^{3}gkg^{-1} h^{-1}, and °C^{-1}, and m^{3}h^{-1}, respectively. All of the parameters may differ from house to house, especially p_1 and p_3, which depend on the emitting surface area.

When the data from those houses for which five or more points are available and those from all the houses are fitted to equation 19, by the method of least squares, we find the following results (Table 23).

The parameters which take on negative (non-physical) values may, given the uncertainties in the fitting procedure, be taken as zero. We see that the values of the parameters do, in fact, differ from house to house.

Table 23. Water Vapor Model Fit and Parameters -- Equation 19

House code	Number Periods	p_1	p_2	p_3	R^2	F
ECD026C	16	3.51	0.01	0.017	0.86	26**
ECD027C	7	0.07	0.19	-0.001	0.96	35**
ESP108	17	16.51	-0.01	0.048	0.63	8*
ESP120	5	0.02	0.24	0.002	0.94	10*
EVA505C	5	0.20	0.09	0.005	0.98	29*
EVA510C	6	2.72	-0.01	0.006	0.74	3
All houses	180	4.64	0.02	0.030	0.54	69**

Since we have no way of knowing the actual values of the parameters for each house, it is necessary to simplify the model. First, we show that the value of p_2 is of little importance. We fit the data for the same houses used above to a two-parameter model based on equation 19 with p_2 fixed at the value obtained from all of the data, i.e., 0.02. We find:

Table 24. Two Parameter Water Vapor Model -- $p_2 = 0.02$

House code	Number Periods	p_1	p_3	R^2	F
ECD026C	16	3.02	0.018	0.86	42**
ECD027C	7	3.07	0.008	0.91	26*
ESP108	17	7.77	0.045	0.63	13*
ESP120	5	3.17	0.012	0.87	10*
EVA505C	5	1.03	0.006	0.89	12*
EVA510C	6	1.17	0.006	0.71	5

When we simply eliminate p_2 from the model, i.e., $p_2 = 0$, we find:

Table 25. Two Parameter Water Vapor Model -- $p_2 = 0$

House code	Number Periods	p_1	p_3	R^2	F
ECD026C	16	3.94	0.016	0.85	40**
ECD027C	7	4.49	0.008	0.90	22*
ESP108	17	12.04	0.047	0.63	13*
ESP120	5	5.35	0.015	0.85	9*
EVA505C	5	1.52	0.006	0.85	8
EVA510C	6	2.01	0.006	0.73	5
All houses	180	6.89	0.028	0.46	76**

There is little or no loss of statistical significance involved in making either of these assumptions, where the individual houses are concerned, i.e., the model is not very sensitive to changes in p_2. However, since the R^2 of the fit to all the data is somewhat diminished when p_2 is taken as 0, we choose to fix it at the value obtained from the fit to all the data, i.e., $p_2 = 0.02$.

Since we are concerned with the normalization of existing data, rather than with the prediction of concentrations from a knowledge of the independent variables, we can eliminate one parameter from the equation through division. Given a measured concentration C_i, we have a standard condition, normalized concentration C_{norm}, where

$$\frac{C_{norm}\left[1+\frac{p_3}{V\lambda_{norm}}\right]-C_{out}}{C_i\left[1+\frac{p_3}{V\lambda}\right]-C_{out}} = \frac{exp\ (p_2\ T_{norm})\ V\lambda}{exp\ (p_2\ T_i)\ V\lambda_{norm}} \qquad [20]$$

where T_{norm} (20 °C) and λ_{norm} (0.5 h^{-1}) are the normalized values of temperature and ventilation rate, respectively. C_{out} is taken as the outdoor concentration for the normalized period. We have now eliminated p_1 from the subsequent work.

We still have the problem of a lack of knowledge of p_3 for the several houses. To circumvent this, we choose to perform *two* normalizations of water vapor, one for the minimum possible p_3 and one for the maximum. When $p_3 = 0$, we have

$$C_{norm} = (C_i - C_{out})\exp\left[p_2(T_{norm} - T_i)\right]\frac{\lambda}{\lambda_{norm}} + C_{out} \qquad [21]$$

and when p_3 becomes infinite, we have

$$C_{norm} = C_i\exp\left[p_2(T_{norm} - T_i)\right]. \qquad [22]$$

We see that the two normalizations represent the extremes of dependence and independence of the ventilation rate. Equations 21 and 22 may be used to predict the post-weatherization concentration on the basis of the baseline (BSL) indoor and outdoor concentrations and the baseline and post-weatherization temperature and exchange rate as was done with radon (equation 19). The predictions of equation 21 have an average absolute residual of 1.05 g kg^{-1}, which is 16% of the mean post-weatherization indoor concentration, and a maximum percentage error of 51%. Figure 37 graphically represents the use of equation 21 to predict post-weatherization concentrations from baseline levels, indoor temperatures, and ventilation rates and from post-weatherization indoor temperatures, ventilation rates, and outdoor concentrations. In Figure 30, the predictions of equation 22 have an average absolute residual of 0.77 g kg^{-1}, which is 12% of the mean post-weatherization indoor concentration, and a maximum percentage error of 34%. For both Figures 37 and 38, relative humidity is computed using the modeled concentrations and indoor temperatures.

Tables 26 and 27 provide the arithmetic mean (AM) and arithmetic standard deviation (ASD) for normalized relative humidity using the two possible techniques of normalization (equations 21 and 22). The first table (Table 26) applies to all the houses; the other table (Table 27) applies to those houses whose specific leakage area has been reduced by at least 20%. In all cases T_{norm} is 20 °C and C_{out} is the outdoor concentration for the normalized period.

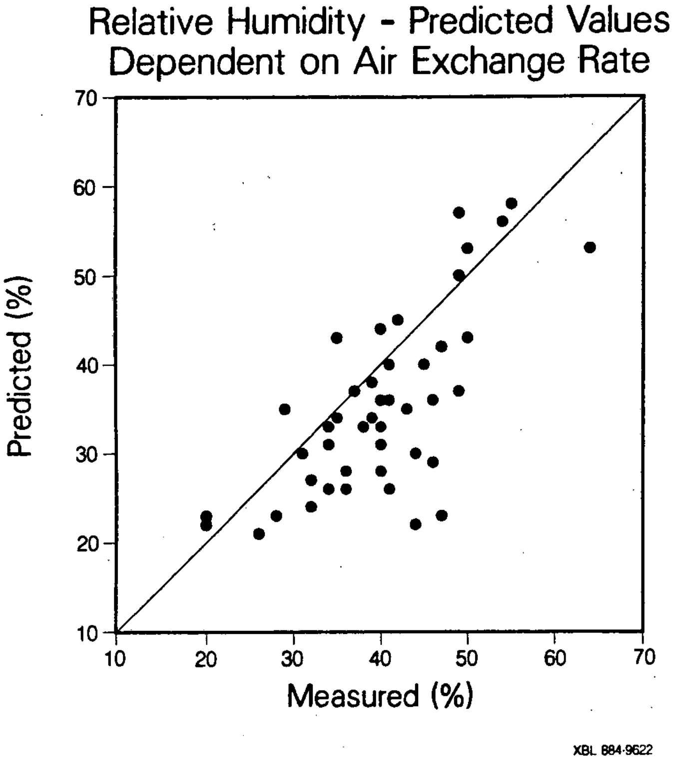

Figure 37 Water vapor model including parameter for ventilation rate generates predicted post-weatherization concentrations using post-weatherization indoor temperatures, outdoor H_2O vapor concentrations, and ventilation rates, plus baseline indoor temperatures, H_2O vapor concentrations, and ventilation rates. Relative humidity is then computed using the indoor temperature and compared against actual measured concentrations during the post-weatherization period.

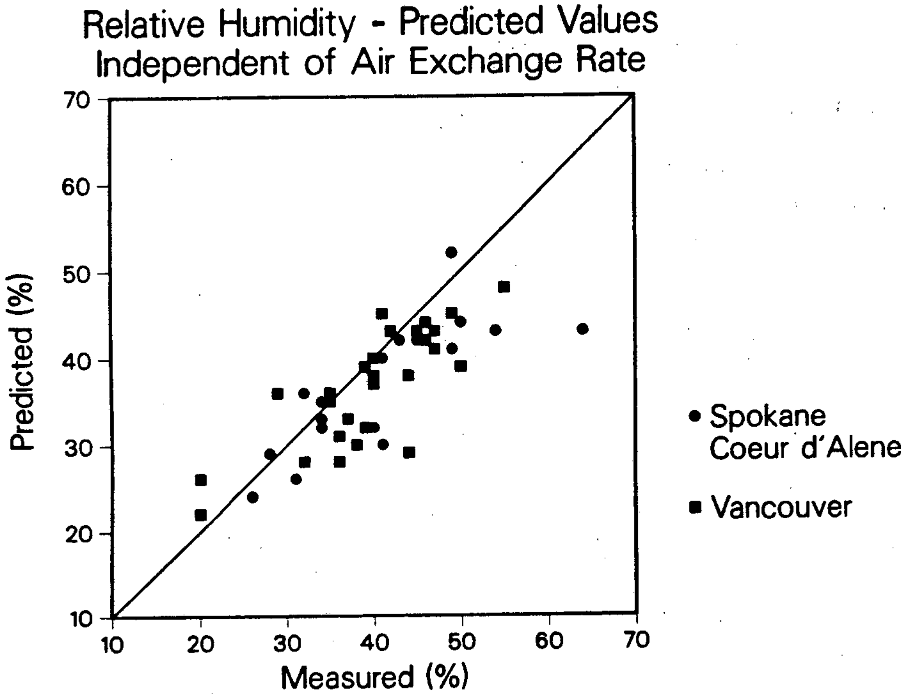

Figure 38 Similar to Figure 37, but water vapor model does not include ventilation rate parameter. Data points are closer to the line of agreement than for the model including ventilation rates. No difference is observed for Vancouver or Spokane/Coeur d'Alene homes.

Table 26. Modeled Pre- and Post-Weatherization Relative Humidity -- All Houses Corrected to Standard Conditions

Site	Equation	Number Periods	Baseline AM (RH)	Baseline ASD	Post-Weatherization AM (RH)	Post-Weatherization ASD	Probability
Spokane/ Coeur d'Alene	21	19	0.36	0.14	0.39	0.10	0.25>P> 0.2
	22	19	0.37	0.10	0.41	0.11	0.2>P>0.1
Vancouver	21	23	0.35	0.10	0.38	0.10	0.2>P>0.1
	22	27	0.36	0.07	0.39	0.10	0.2>P>0.1
All sites	21	42	0.36	0.08	0.38	0.10	0.45>P>0.25
	22	46	0.37	0.08	0.40	0.10	0.1>P>0.05

As seen in both tables, indoor humidities (and water vapor concentrations) always showed an increase after weatherization, regardless of the model used or the region. Changes in indoor levels ranged from approximately 5% to 24%, with the later resulting from the model independent of ventilation rate (equation 22) applied to the five houses that received house-doctor retrofits (Table 27). This large increase for the house-doctored homes and the increase of 8% for all houses using equation 22 (Table 26) were the only statistically significant increases. No changes due to the ventilation-dependent model (equation 21) were significant. Once again, all of these results are based on models that may have large predictive uncertainties. And for the case of water vapor, the models do not directly account for occupant activities that have a large impact on the indoor source strength of water vapor. Nevertheless, the fact that all predicted levels increased for post-weatherization, and the fact that the range of increases bound the decrease in SLA (12.5%) suggests that weatherization may have been the cause of the change in indoor humidity levels.

Table 27. Modeled Pre- and Post-Weatherization Relative Humidity --
SLA Changed $\geq$ -20%
Corrected to Standard Conditions

Site	Equation	Number Periods	Baseline		Post-Weatherization		Probability
			AM	ASD	AM	ASD	
			(RH/g/kg)		(RH/g/kg)		
Spokane/ Coeur d'Alene	21	11	0.36/5.55	0.13/1.81	0.40/6.27	0.10/1.61	0.25>P>0.2
	22	11	0.37/5.49	0.09/0.64	0.42/6.32	0.12/1.18	0.2>P>0.1
Vancouver	21	6	0.36/5.62	0.11/1.28	0.40/6.12	0.10/1.12	0.45>P>0.25
	22	6	0.35/5.37	0.08/0.42	0.38/5.84	0.07/0.82	0.2>P>0.1
All sites	21	17	0.36/5.58	0.12/1.64	0.40/6.22	0.10/1.46	0.2>P>0.1
	22	17	0.36/5.45	0.09/0.58	0.40/6.15	0.11/1.09	0.2>P>0.1
					(Post-House Doctor)		
House doctor	21	5	0.36/6.18	0.07/1.87	0.40/6.86	0.07/0.89	0.25>P>0.2
	22	5	0.34/5.66	0.07/0.63	0.42/7.26	0.04/0.62	0.1>P>0.05

Formaldehyde

A physical mass balance model by Matthews *et al.*, (1986b), following earlier work by Andersen *et al.*, (1975), and Berge *et al.*, (1980), characterizes the steady-state source strength in equation 2 as;

$$S = K_B \, A \, (C_B - C_i) \; , \qquad [23]$$

where

K_B = transfer coefficient,

A = area of emitting material (m^2),

C_i = indoor vapor concentration (ppb), and

C_B = bulk phase vapor concentration, where

$$C_B = f(T)\, g(RH)\, C_{bnorm} \ , \qquad [24]$$

where

T = indoor temperature (°K),

RH = indoor relative humidity, and

C_{bnorm} = bulk phase vapor concentration at standard T and RH.

Combining equations 2, 23, 24,

$$C_i = q_2 \frac{[f(T)\, g(RH)\, C_{bnorm} - C_i]}{V\lambda} + C_{out} \ , \qquad [25]$$

where $q_2 = K_B A$. From Matthews,

$$f(T) = e^{-q_4 \left[\frac{1}{T_i} - \frac{1}{T_{norm}} \right]}, \qquad [26]$$

and

$$g(RH) = \left[\frac{RH}{RH_{norm}} \right]^{q_3} . \qquad [27]$$

At standard conditions; $f(T) = 1$, $g(RH) = 1$, $C_i = C_{norm}$, $C_{out} = 0$ and $\lambda = \lambda_{norm}$, so that

$$C_{bnorm} = \frac{C_{norm}(V\lambda_{norm} + q_2)}{q_2} . \qquad [28]$$

Finally, combining equations 25-28, the indoor concentration is given by

$$C_i = q_1 \left[\frac{V\lambda_{norm} + q_2}{V\lambda + q_2} \right] \left[\frac{RH}{RH_{norm}} \right]^{q_3} \exp\left\{ -q_4 \left[\frac{1}{T_i} - \frac{1}{T_{norm}} \right] \right\} + \frac{V\lambda C_{out}}{V\lambda + q_2} \qquad [29]$$

where q_1, q_2, and q_4 are parameters with units ppb (vol/vol), m^3h^{-1}, $°K^{-1}$, respectively, and q_3 is a dimensionless parameter. T_{norm} is 296 °K, RH_{norm} is 0.5, and λ_{norm} is 0.5 h^{-1}.

This equation presents similar problems to the equation governing water vapor concentration, with the additional complication of a fourth parameter.

As with the water vapor data, we fit the formaldehyde data to the model using the method of least squares, with the following results (Table 28).

Table 28. Formaldehyde Model -- Fit and Parameter Values

House code	Number Periods	q_1	$q_2(x10^3)$	q_2	$q_3(x10^4)$	R^2	F
ECD026C	16	87	1.78	1.16	0.72	0.73	9*
ECD027C	7	36	0.43	0.69	0.62	0.54	1
ESP108	18	20	0.51	0.61	0.00	0.29	1
ESP120	5	17	1.66	1.45	0.00	0.80	1
EVA505C	5	65	∞	0.21	0.87	0.95	5
EVA510C	6	19	0.24	-0.20	0.22	0.61	1
EVA604	7	47	0.21	0.99	0.71	0.69	2
Spokane/ Coeur d'Alene	107	40	0.33	0.87	0.69	0.20	7*
Vancouver	74	40	0.23	0.32	0.49	0.18	4
All houses	181	44	0.31	0.77	0.80	0.22	13*

The statistical significance of the fits is relatively low indicating deficiencies in the model and/or measurements.

In order to develop a normalization equation, we must set two of the parameters equal to the values obtained from the fit to all the data. One parameter may be eliminated from the equation, leaving one which will be allowed to vary over the range of physically permissible values. It is most convenient to eliminate q_1 by division, and it is clear that q_2 differs widely from house to house, so it remains to make the assumptions that $q_3 = 0.77$ and $q_4 = 0.80 \times 10^4$ based on the fits in Table 28. Fitting the data to equation 29 with two parameters yields the following table:

Table 29. Two-Parameter Formaldehyde Model -- $q_3 = 0.77$ and $q_4 = 0.80 \times 10^4$

House code	Number Periods	q_1	$q_2(\times 10^3)$	R^2	F
ECD026C	16	84	1.63	0.60	11*
ECD027C	7	39	0.42	0.58	3
ESP108	18	24	0.33	0.31	4
ESP120	5	25	∞	0.08	0
EVA505C	5	82	∞	0.71	4
EVA510C	6	22	0.14	0.55	2
EVA604	7	47	0.20	0.68	5
Spokane/ Coeur d'Alene	107	40	0.30	0.22	15*
Vancouver	74	54	∞	0.13	5

It is apparent that q_2 is highly dependent on the values chosen for q_3 and q_4, but the statistical significance of the results does not change greatly.

Elimination of q_1 from equation 29 and introduction of the chosen values of q_3 and q_4 yields

$$\frac{(V\lambda_{norm} + q_2)C_{norm} - V\lambda C_{norm}}{(V\lambda + q_2)C_i - V\lambda C_{out}} = \left[\frac{RH_{norm}}{RH}\right]^{0.77} \exp\left\{8000\left[\frac{1}{T_{norm}} - \frac{1}{T_i}\right]\right\}. \quad [30]$$

The limits of q_2 are zero and infinity. In the former case we have

$$C_{norm} = (C_i - C_{out}) \frac{\lambda}{\lambda_{norm}}\left[\frac{RH_{norm}}{\mathrm{RH}}\right]^{0.77} \exp\left\{-8000\left[\frac{1}{T_{norm}} - \frac{1}{T_i}\right]\right\} + C_{out} \quad [31]$$

while in the latter we have

$$C_{norm} = C_i\left[\frac{RH_{norm}}{\mathrm{RH}}\right]^{0.77} \exp\left\{-8000\left[\frac{1}{T_{norm}} - \frac{1}{T_i}\right]\right\} \quad [32]$$

Equation 31, like equation 21, shows a concentration directly dependent on ventilation rate, while equation 32, like equation 22, shows a concentration completely independent of ventilation rate. These are the extreme possibilities.

Since the normalized formaldehyde concentration is dependent on relative humidity, which is itself dependent on normalized water vapor, there are four possibilities, namely 1) water vapor and formaldehyde both dependent on ventilation rate (eqns 21 and 31); 2) water vapor dependent on ventilation rate and formaldehyde independent of ventilation rate (21 and 32); 3) water vapor independent of ventilation rate and formaldehyde dependent on ventilation rate (22 and 31); 4) both water vapor and formaldehyde independent of ventilation rate (22 and 32). The phrase "formaldehyde independent of ventilation rate" is here taken to mean that formaldehyde has no direct dependence on ventilation rate, but is possibly indirectly dependent through its dependence on relative humidity (water vapor concentration), which may depend on ventilation rate.

When equations 31 and 32 are used to predict the post-weatherization concentrations on the basis of the measured baseline concentrations and humidity, the predicted post-weatherization humidity, and the measured temperatures, we find, for the four cases listed above, ratios of the mean absolute residual to the mean concentration of 39%, 23%, 35%, and 23%, and maximum ratios of residual to mean of 100%, 77%, 137% and 113%. Case 2 appears to provide the best results, but the use of predicted humidities which are dependent on ventilation rates is inconsistent with the results of the previous section, in which it was seen that the predicted water vapor concentrations (and humidities) that were independent of ventilation rate were closer to the measured values.

Figures 39-42 depict graphically the models' agreement with actual measured concentrations. Figure 40 supports the statistical data that indicate case 2 provides the best results. The physical explanation for the model without ventilation performing best is unknown, although it could be due to the uncertainties in the ventilation rate measurement causing additional uncertainties in the model. There appears to be more scatter in the data for the Vancouver homes (Figure 42).

In the following tables (Tables 30 and 31) we provide the geometric mean (GM) and geometric standard deviation (GSD) for normalized formaldehyde using the four possible techniques of normalization. The first table applies to all the houses; the remaining table applies to those houses whose specific leakage area was reduced by at least 20%. In all cases the normal temperature, relative humidity, and exchange rate are 20 °C, 0.5, and 0.5 h^{-1}, respectively.

For most of the before and after weatherization comparisons, there is very little difference between the mean HCHO levels, even for those homes with large reductions in SLA. Only in the house-doctored structures in there a significant difference between means (35%) when using model equations 22 and 32. It is obvious from the data, that for this small set of five homes there are large predictive differences between the equations, particularly for the HCHO model independent of ventilation rates (equation 32) when applied to the post-weatherization concentrations. This may result from the large changes in measured HCHO levels (baseline mean = 29 ppb, post-house doctor mean = 48 ppb) and ventilation rates (baseline PFT mean = $0.41 h^{-1}$, post-house doctor mean = $0.30\ h^{-1}$) after house-doctoring these five buildings. Therefore, the model without the ventilation term would be unable to account for or predict a large change.

To test the response of the predicted indoor HCHO concentration on a small change in ventilation, consider applying equation 31 to the data from house EVA646 (Table 32).

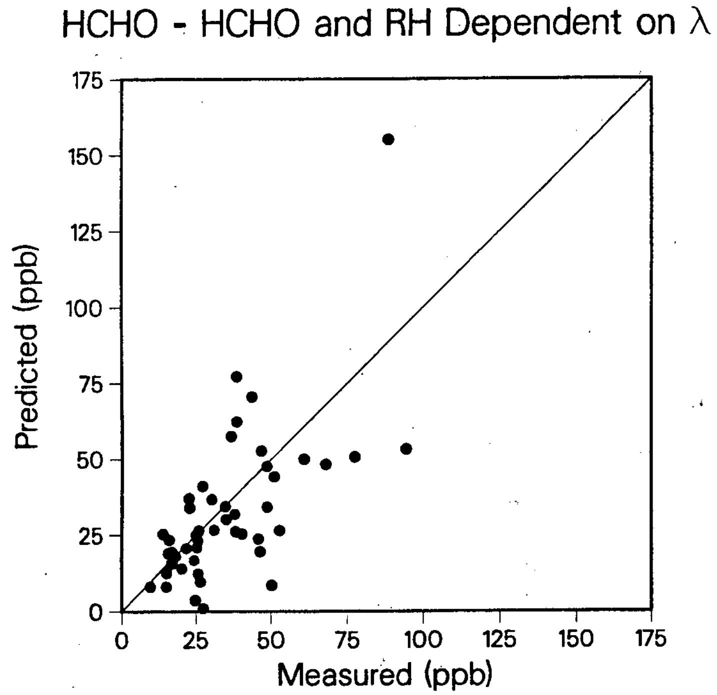

Figure 39 Formaldehyde predictions for post-weatherization that include a ventilation parameter in both the formaldehyde and water vapor models. Model uses baseline concentrations, humidity, and temperature. (Case 1)

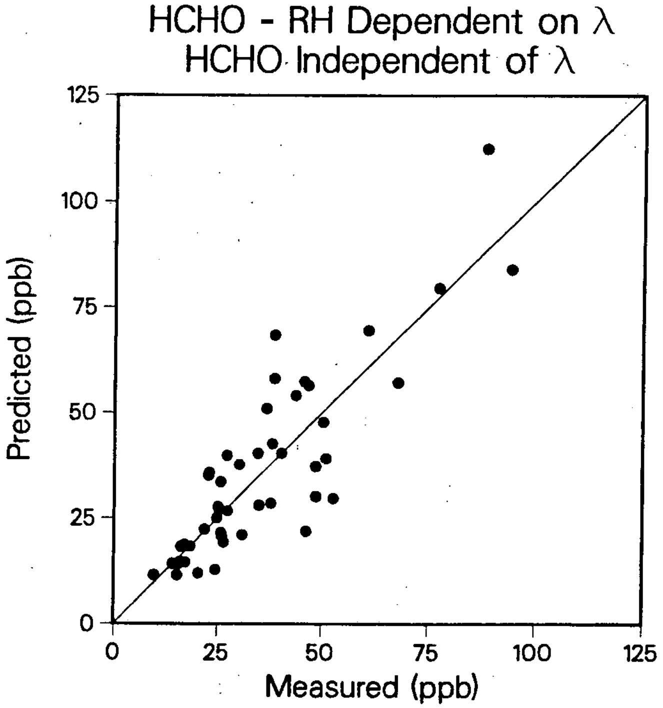

Figure 40 Similar to Figure 39, but formaldehyde prediction does not include a ventilation parameter in the formaldehyde model (Case 2). This model produces closest agreement to measured values.

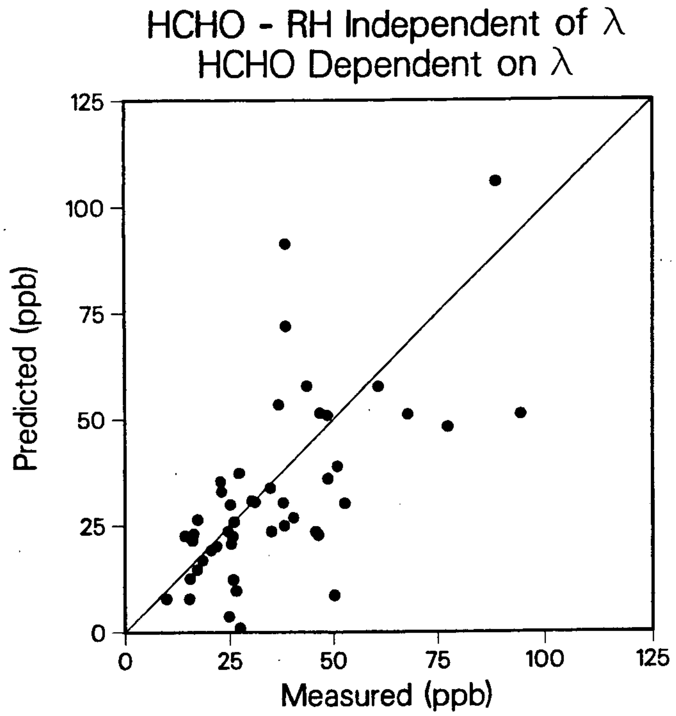

Figure 41 Similar to Figure 39, but formaldehyde prediction does not include a ventilation parameter in the water vapor model (Case 3).

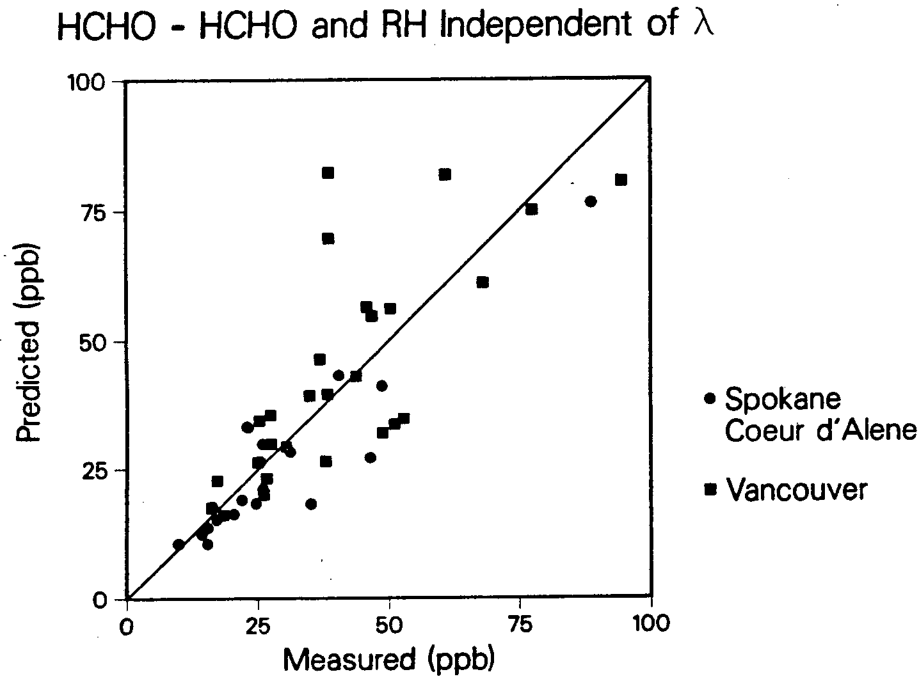

Figure 42 Similar to Figure 39, but formaldehyde model prediction is totally independent of a ventilation rate parameter (Case 4). Data for the Vancouver area homes appear to have more scatter than for the Spokane/Coeur d'Alene homes.

First, the post-weatherization HCHO concentration was calculated using the measured data (including measured RH), yielding 25.9 ppb -- very close to the actual concentration of 26.1 ppb. Then, if we assume that the ventilation rate during the post-weatherization period was actually an additional 15% lower (0.46 h^{-1}) than the measured rate of 0.54 h^{-1}, and with all other data values held constant, the recalculated post-weatherization HCHO concentration is 29.5 ppb. This change in concentration is 14% greater than the original prediction, and within the measurement accuracy of the HCHO passive sampler. However, if predicted post-weatherization RH levels from equations 21 and 22 are used, additional uncertainties in the predicted HCHO levels result. When these predicted RH levels are applied to the measured post-weatherization data (including the ventilation rate of 0.54 h^{-1}), the predicted HCHO levels ranged from 7% below to 17% above the actual measured concentration.

The formaldehyde model is quite complex and requires many data for successful prediction. We also suspect that, as in the case of radon, indoor concentrations depend on these variables in a very house-specific way. Consequently, this attempt to create a general model for all study houses results in greater predictive uncertainty. Insufficient measurement data on each house prohibits the creation of a model for each building, with only a few exceptions. Until studies involving many more homes, or more measurement periods on each house are conducted, the effects of weatherization house-tightening on indoor HCHO levels will remain uncertain.

Table 30. Modeled Pre- and Post-Weatherization Formaldehyde Concentrations -- All Houses, Corrected to Standard Conditions

Site	Equation	Number Periods	Baseline GM (ppb)	Baseline GSD	Post-Weatherization GM (ppb)	Post-Weatherization GSD	Probability
Spokane/ Coeur d'Alene	21,31	19	23.55	1.45	24.47	1.55	0.45>P>0.25
	21,32	19	30.29	1.63	30.58	1.63	P>0.9
	22,31	19	23.97	1.61	24.10	1.70	P>0.9
	22,32	19	29.04	1.48	29.40	1.55	P>0.9
Vancouver	21,31	23	35.31	1.63	34.22	1.76	0.45>P>0.25
	21,32	27	45.33	1.59	40.25	1.61	0.45>P>0.25
	22,31	23	35.98	1.76	34.66	1.82	0.45>P>0.25
	22,32	27	42.52	1.46	39.81	1.51	0.45>P>0.25
All sites	21,31	42	29.40	1.61	29.40	1.70	P>0.9
	21,32	46	37.37	1.65	35.93	1.64	0.45>P>0.25
	22,31	42	29.94	1.75	29.40	1.81	0.45>P>0.25
	22,32	46	36.32	1.53	35.13	1.56	0.45>P>0.25

Table 31. Modeled Pre- and Post-Weatherization Formaldehyde Concentrations -- SLA Changed ≥-20% Corrected to Standard Conditions

Site	Equations	Number Periods	Baseline GM (ppb)	Baseline GSD	Post-Weatherization GM (ppb)	Post-Weatherization GSD	Probability
Spokane/ Coeur d'Alene	21,31	11	23.95	1.36	24.48	1.59	0.45>P>0.25
	21,32	11	27.74	1.44	27.98	1.41	P>0.9
	22,31	11	24.93	1.59	24.65	1.80	P>0.9
	22,32	11	27.02	1.27	27.55	1.39	0.45>P>0.25
Vancouver	21,31	6	42.34	1.61	38.20	2.00	0.45>P>0.25
	21,32	6	45.09	1.64	41.14	1.60	0.45>P>0.25
	22,31	6	43.81	1.68	39.17	2.00	0.45>P>0.25
	22,32	6	46.01	1.54	42.42	1.54	0.45>P>0.25
All sites	21,31	17	29.29	1.58	28.64	1.78	P>0.9
	21,32	17	32.93	1.60	32.06	1.53	0.45>P>0.25
	22,31	17	30.42	1.72	29.03	1.91	0.45>P>0.25
	22,32	17	32.60	1.50	32.08	1.52	P>0.9
					(Post-House Doctor)		
House Doctor	21,31	5	27.32	1.35	30.96	1.81	0.45>P>0.25
	21,32	5	30.97	1.83	45.57	1.37	0.2>P>0.1
	22,31	5	29.47	1.66	30.16	1.89	P>0.9
	22,32	5	32.16	1.38	43.49	1.28	0.1>P>0.05

Table 32. EVA646 Sensitivity of Calculated HCHO to 15% Change in Ventilation Rate Using Equation 31

Parameter	Measured Baseline	Measured Post-WXTN	Calculated Post-WXTN			Recalculated Post-WXTN (λ/-15%)		
			Measured RH	RH from Eqn 21	RH from Eqn 22	Measured RH	RH from Eqn 21	RH from Eqn 22
C (ppb)	34.4	26.1	25.9	30.4	24.2	29.5	35.9	27.4
C_{out}	5.5	.5	-	-	-	-	-	-
RH	0.32	.55	0.55	0.71	0.49	0.55	0.75	0.49
PFT Ventilation (h^{-1})	0.63	.54	-	-	-	(0.46)	(0.46)	(0.46)
T (°C)	24.0	14.2	-	-	-	-	-	-

V. WEATHERIZATION COSTS

Data on the costs of weatherization were collected from the participating utility companies and weatherization contractors. Appendix D is a compilation from the contractor bid sheets of the weatherization work performed on each house and its associated costs. The amount of house-specific detail varies from one utility district to another. But it generally includes type, number and size of window retrofits; type, area coverage, and amount of insulation added; lineal feet of caulking and weatherstripping; application of duct sealing and insulation; addition of attic and crawlspace ventilation; and total cost. A separate table covers the work performed during the house doctor retrofit. There have been no attempts made to correlate and analyze the impact of various weatherization measures (other than wall insulation and house doctoring) on building tightness or indoor pollutant concentrations.

Table 33 summarizes the costs of weatherization from Appendix D. BPA standard weatherization averaged approximately $2500 for the 26 homes without wall insulation and $3400 for 13 of those homes also receiving wall insulation. However, the differences between the two groups does not necessarily imply the cost of wall insulation since the number of homes is small and there was considerable variation in the cost of the standard weatherization. House doctoring cost between $500 and $900 per house and averaged $737.

Table 33. Costs of Weatherization

		Spokane/Coeur d'Alene		Vancouver	All	
BPA Weatherization Without Wall Insulation:	No	12		14	26	
	Avg. BPA Cost ($)	1124		2392	1807	
	Avg. Total Cost ($)	1627		3185	2466	
BPA Weatherization With Wall Insulation:	No	7*	8	6	13*	14
	Avg. BPA Cost ($)	3079	-	2215	2680	-
	Avg. Total Cost ($)	3643	3374	3084	3385	3250
All Homes:	No.	19*	20	20	39*	40
	Avg. BPA Cost ($)	1844	-	2339	2098	-
	Avg. Total Cost ($)	2370	2326	3155	2772	2741
	Avg. Unit Cost ($/ft^2 - occupied space)	1.965		2.317	2.141	
House Doctor:	No	2		3	5	
	Avg. Cost ($)	552		860	737	
	Avg. Unit Cost ($/ft^2 - occupied space)	0.579		0.735	0.673	

*Does not include home where owner assumed entire cost of weatherization. House was not in BPA service area.

VI. SUMMARY

Data from a regional indoor air quality survey in 111 Vancouver, Spokane, and Coeur d'Alene homes indicate that, except for radon, indoor pollutant concentrations were generally low. Very few of these homes exhibited elevated levels of HCHO, H_2O or NO_2. The very low NO_2 levels can be explained since the vast majority of the homes were electrically-heated and had no combustion appliances. Formaldehyde concentrations were low, probably because these existing homes were generally older structures. Radon concentrations were high inside many Spokane River Valley homes, due primarily to the convective flow of radon-bearing soil gas from a highly permeable local soil.

The 48 homes that participated in the weatherization sensitivity phase of this project were generally representative of Pacific Northwest housing. BPA's standard weatherization program appears to have reduced the SLA of the 40 weatherized structures approximately 12.5%, while the reduction due to wall insulation was not statistically significant. More intensive weatherization through house doctoring resulted in an additional reduction of 26% in leakage area. As observed in other studies, there was poor agreement between the PFT-measured ventilation rates and ventilation rates predicted by the LBL model. The difference between the geometric means of the two techniques was 20%. The geometric mean PFT-measured ventilation rate was 0.37 h^{-1} for the baseline condition and 0.39 h^{-1} for post-weatherization periods, although these data are not corrected to standard environmental conditions.

As in the screening survey, pollutant concentrations displayed regional differences, with Vancouver area homes generally having higher HCHO and water vapor concentrations, while radon levels were higher in Spokane/Coeur d'Alene homes. Indoor water vapor concentrations demonstrated a strong dependence on outdoor levels. However, possibly because of depleted free HCHO in the aged materials in these homes, indoor air HCHO levels showed little correlation to indoor water vapor levels. Indoor nitrogen dioxide concentrations were also very low in these homes, because few unvented combustion appliances were in use. Indoor NO_2 levels remained low, even when outdoor concentrations were elevated. Respirable suspended particle concentrations were usually high only in those homes where tobacco smoking occurred or where fireplaces or woodstoves were frequently used. Indoor levels could be quite high (up to 435 $\mu g/m^3$) in these homes as could outdoor levels during periods of temperature inversion. However, correlation was poor between indoor RSP and outdoor RSP levels, indicating that these small particles are removed from the outdoor ventilation air as it passes into the house. Pollutants were distributed uniformly within each house -- pointing to good mixing of the indoor air.

Comparisons of changing indoor pollutant concentrations to changing ventilation rates show that indoor pollutant levels are influenced more by factors other than ventilation, such as pollutant source strengths, occupant effects, and environmental conditions. Simplified models were developed to evaluate the effects of weatherization on indoor pollutant concentrations. The results of the modeling effort imply that average changes in the indoor concentrations of radon, water vapor, and formaldehyde are quite small due to the effects of standard weatherization house-tightening techniques. This supports the observation of poor correlation between changes in measured pollutant levels and changes in measured ventilation rates, possibly because changes in ventilation rates were usually small. In individual houses with greater changes in house air leakage area after weatherization or with stronger indoor pollutant sources, changes in indoor pollutant levels may be larger.

Only in crawlspace homes, where ventilation was added to the crawlspace as part of the weatherization process, were the levels of indoor radon significantly reduced. It is possible that some house-tightening retrofits changed the distribution of air leakage sites and reduced radon entry in homes with other substructure types.

Except for respirable suspended particle concentrations, concentrations of other indoor combustion-related pollutants (CO and NO_2) in this study were low. In regions where unvented combustion appliances are prevalent, indoor levels of these pollutants (including CO_2) may exhibit larger increases after weatherization that includes house-tightening (Traynor, *et al.* 1987).

It should be noted that while it appears standard weatherization had a very small impact on indoor air quality parameters, these conclusions should be considered preliminary until additional studies resolve the following issues: 1) improving upon the relatively high uncertainty in the pollutant measurement techniques (particularly the passive monitors) as compared with the small changes in ventilation rates (and pollutant concentrations) resulting from weatherization, 2) the usefulness of a larger study involving a greater number of homes that would allow a more robust statistical evaluation either in conjunction with or independent of a laboratory-based study using controlled experiments to validate general indoor air quality models incorporating changing leakage area distributions, and 3) the development of more sophisticated models that include more of the parameters that are important for describing the house environment.

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APPENDIX A

DATA SUMMARY SCREENING SURVEY

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DATA SUMMARY SCREENING SURVEY

HOUSE ID#	PRIMARY HEAT	NO. OF STORIES	SIZE (ft^2)	CONSTRUCTION MATERIALS (a)	WEATHERIZED (b)	WALL INSULATION	AGE	REMODEL YEAR	BASEMENT	CRAWLSPACE	SLAB	UFFI (c)	NO. OF SMOKERS	WOODSTOVE	OTHER (d)	HCHO (ppb)	NO_2 (ppb)	H_2O (g/kg)	Rn (pCi/l)	SELECTED FOR FURTHER TESTING
ECD 26C	ELEC	2	1807	W	MOST	Y	13	-	Y	Y	-	-	0	Y	FP	-	-	-	14.0	Y
ECD 27C	ELEC	2	2688	W	LITTLE	Y	85	-	Y	Y	-	-	0	FURN	FP	-	-	-	29.0	Y
ECD 141	ELEC	1	1380	W	SOME	Y	62	1948	-	Y	-	-	2	-	FP	-	-	-	1.9	N
ECD 142	ELEC	2	1728	W	SOME	Y	13	-	Y	Y	Y	-	2	Y	-	-	-	-	27.9	N
ECD 143	ELEC	2	1292	W	LITTLE	N	46	-	-	Y	-	-	0	-	-	-	-	-	12.5	Y
ECD 144	ELEC	1+	1050	W	SOME	N	64	-	Y	Y	-	-	0	-	-	-	-	-	7.4	Y
ECD 145	ELEC	1	1920	W	MOSTLY	Y	10	-	Y	-	-	-	1	Y	-	-	-	-	3.0	Y
ECD 146	ELEC	2	1292	W	LITTLE	N	59	1973	Y	Y	-	-	0	Y	KER	-	-	-	9.2	Y
ECD 147	ELEC	2	1398	W	LITTLE	N	92	1904	-	Y	-	-	0	-	-	-	-	-	3.6	Y
ECD 148	ELEC	1	1365	CON	SOME	Y	40	-	-	Y	-	-	0	-	FP	-	-	-	10.4	N
ECD 149	ELEC	1+	819	W	LITTLE	N	40	-	Y	Y	Y	-	0	Y	-	-	-	-	10.4	Y
ECD 150	ELEC	2	720	W	LITTLE	N	50	-	Y	-	-	-	2	Y	-	-	-	-	18.0	Y
ECD 151	ELEC	2	1344	W	LITTLE	N	50	-	Y	Y	-	-	1	-	FP	-	-	-	2.5	Y
ECD 152	ELEC	1	736	W	MOST	N	28	-	-	Y	-	-	0	-	-	-	-	-	1.5	Y
ECD 153	ELEC	1	1164	W	LITTLE	Y	10	-	Y	Y	-	-	2	Y	-	-	-	-	17.0	Y
ESP 1C	GAS	1	750	W	SOME	Y	35	1983	Y	-	-	-	0	-	-	18	10	5.23	1.05	-
ESP 2C	GAS	1	820	W	SOME	Y	38	1980	Y	-	-	-	1	-	FP	17	4	4.91	3.72	-
ESP 3C	ELEC	2	2500	W	SOME	Y	60	1984	Y	-	-	?	1	Y	-	45	9	4.25	0.87	Y
ESP 4C	ELEC	1	2000	W	SOME	Y	7	-	Y	-	Y	-	0	Y	-	32	3	5.08	1.58	Y
ESP 5C	ELEC	2	2000	W	YES	Y	7	-	Y	-	-	-	0	-	-	32	3	5.24	5.72	-
ESP 6C	GAS	2	2000	W	SOME	Y	74	-	Y	-	-	-	1	Y	FP	20	4	5.03	2.67	-
ESP 7C	OIL	2	2550	W	YES	Y	58	1984	Y	-	-	-	0	-	-	17	9	4.81	2.42	-
ESP 101	ELEC	2	2349	W	SOME	Y	15	1979	Y	-	-	-	0	-	FP	32	8	4.97	12.60	Y
ESP 10C	ELEC	1	2536	W	SOME	N	29	-	Y	-	-	-	1	Y	-	57	19	7.34	27.18	Y
ESP 103	ELEC	1	880	W	SOME	Y	24	-	-	Y	-	-	2	-	-	37	D	9.19	5.12	Y
ESP 104	ELEC	1+	1904	W	SOME	Y	12	-	Y	Y	-	-	0	-	FP	18	4	4.80	5.99	Y
ESP 105	ELEC	2	2350	W	MOST	Y	4	-	Y	-	-	-	0	-	FP	47	3	4.78	1.35	-
ESP 106	ELEC	1+	2099	W	MOST	Y	6	1983	Y	Y	-	-	4	-	-	CANCELLED OUT				
ESP 107	ELEC	2	1927	W	MOST	Y	8	1984	Y	-	-	-	1	-	FP	32	3	5.32	4.94	-
ESP 108	ELEC	1	4095	W	SOME	Y	29	81/83	Y	-	-	-	0	-	FP	15	5	5.11	8.08	Y
ESP 109	ELEC	1	1928	W	MOST	Y	8	-	Y	-	-	-	0	Y	-	26	5	5.64	3.11	Y
ESP 110	ELEC	1+	2096	W	MOST	Y	6	-	Y	-	-	-	0	-	-	30	7	5.13	7.60	-
ESP 111	ELEC	2	2619	W	MOST	Y	6	-	Y	-	-	-	0	-	-	50	8	5.50	11.86	-
ESP 112	ELEC	1+	1894	W	MOST	Y	8	1984	Y	-	-	-	0	Y	-	67	1	5.92	5.67	-
ESP 113	ELEC	1+	2435	W	MOST	Y	16	-	Y	-	Y	-	0	-	-	29	6	5.64	12.54	-
ESP 114	ELEC	2	2990	W	SOME	Y	27	1982	Y	Y	-	-	0	-	FP	36	5	5.37	4.32	Y
ESP 115	ELEC	1	3314	W	SOME	Y	6	1983	Y	-	-	-	1	Y	-	33	7	5.11	1.82	Y
ESP 116	ELEC	1	2062	W	SOME	Y	10	1978	Y	-	-	-	0	-	FP	67	2	6.39	14.16	Y
ESP 117	ELEC	1	1476	W	SOME	Y	12	1982	Y	Y	-	-	2	-	PROP	45	28	D	9.36	Y
ESP 118	ELEC	1	944	W	MOST	Y	SAMPLERS NOT RETURNED													
ESP 119	ELEC	2	1826	W	SOME	Y	8	-	Y	Y	-	-	0	-	KER	75	3	6.04	44.70	N
ESP 120	ELEC	2	2154	W	LITTLE	N	66	-	Y	-	-	-	0	-	FP	-	-	-	85.00	Y
ESP 121	ELEC	2	1512	W	SOME	Y	8	M	Y	-	-	-	M	M	FP	53	6	6.84	10.15	N
ESP 122	ELEC	1	794	W	MOSTLY	Y	5	-	Y	-	-	-	2	-	-	67	4	4.92	14.40	N
ESP 123	ELEC	1	924	W	SOME	Y	20	1984	-	Y	-	-	1	-	-	23	10	-	6.60	N

APPENDIX A
DATA SUMMARY SCREENING SURVEY (continued)

HOUSE ID#	PRIMARY HEAT	NO. OF STORIES	SIZE (ft^2)	CONSTRUCTION MATERIALS (a)	WEATHERIZED (b)	WALL INSULATION	AGE	REMODEL YEAR	BASEMENT	CRAWLSPACE	SLAB	UFFI (c)	NO. OF SMOKERS	WOODSTOVE	OTHER (d)	HCHO (ppb)	NO_2 (ppb)	H_2O (g/kg)	Rn (pCi/l)	SELECTED FOR FURTHER TESTING
EVA 501C	ELEC	1	1750	W	SOME	Y	13	1984	-	Y	-	-	0	-	FP	136	5	7.98	0.91	-
EVA 502C	ELEC	1+	1600	W	NO	Y	8	-	-	Y	?	-	0	Y	FP	49	1	D	1.14	-
EVA 503C	ELEC	2	2700	W	YES	Y	30	1980	-	-	Y	-	0	Y	-	26	9	6.26	1.29	-
EVA 504C	ELEC	2	2200	W	SOME	Y	1	-	-	Y	Y	-	0	Y	-	60	5	6.55	1.04	-
EVA 505C	ELEC	1	1700	W	NO	Y	11	81/83	-	Y	Y	-	0	-	FP	62	16	6.93	0.74	Y
EVA 506C	ELEC	1	1600	W	NO	Y	6	-	-	Y	Y	-	2	-	FP	47	6	7.03	0.79	-
EVA 507C	ELEC	1	1900	W	YES	Y	8	-	-	Y	Y	-	0	-	FP	69	1	6.96	0.41	-
EVA 508C	ELEC	1	1885	W	NO	Y	11	-	-	Y	-	-	0	-	-	65	11	7.19	1.55	-
EVA 509C	ELEC	2	1400	W	SOME	Y	45	1982	Y	-	-	-	0	Y	-	20	5	6.00	0.91	Y
EVA 510C	ELEC	1	1400	W	SOME	Y	18	1984	-	Y	Y	-	0	Y	-	36	1	8.15	1.51	Y
EVA 601	ELEC	2	2867	W	LITTLE	Y	12	-	Y	-	-	-	0	-	-	44	8	6.81	1.09	-
EVA 602	ELEC	2	2856	W	SOME	Y	21	1977	Y	-	-	-	1	-	FP	38	3	5.71	1.29	-
EVA 603	ELEC	2	1617	W	SOME	Y	69	-	Y	-	-	-	0	-	-	21	3	6.54	1.51	-
EVA 604	ELEC	1	892	W	LITTLE	N	33	-	-	-	Y	-	2	-	-	59	6	8.66	5.83	Y
EVA 605	ELEC	1	1984	W	LITTLE	Y	17	-	-	Y	-	-	1	-	-	36	10	6.79	1.42	-
EVA 606	ELEC	2	1944	W	SOME	Y	16	-	-	Y	-	-	0	-	-	55	4	6.63	1.03	-
EVA 607	ELEC	2	3352	W	SOME	Y	15	-	-	-	-	-	1	Y	FP	17	4	6.65	0.23	-
EVA 608	ELEC	2	1517	W	SOME	Y	36	81/83	Y	-	-	-	0	-	-	23	5	6.70	1.29	-
EVA 609	ELEC	1	1098	W	SOME	Y	7	-	-	-	Y	-	0	-	FP	47	5	7.02	0.80	-
EVA 610	ELEC	1	882	W	LITTLE	N	40	1984	-	Y	-	-	1	-	-	21	8	6.95	2.85	-
EVA 611	ELEC	1	1975	W	SOME	Y	12	1982	Y	-	-	-	0	-	-	30	5	6.06	1.39	Y
EVA 612	ELEC	2	2836	W	SOME	Y	18	-	Y	-	-	-	0	-	FP	42	12	6.37	1.35	-
EVA 613	ELEC	1+	1924	W	SOME	Y	CANCELLED OUT													
EVA 614	ELEC	1	1373	W	SOME	Y	25	-	-	Y	-	-	1	Y	-	33	7	5.91	1.83	-
EVA 615	ELEC	2	2182	W	SOME	N	61	-	Y	Y	-	-	2	Y	-	58	5	6.78	1.51	Y
EVA 616	ELEC	1	1447	W	SOME	Y	13	-	Y	-	-	-	2	-	-	30	3	7.50	0.68	-
EVA 617	ELEC	1	1008	W	LITTLE	N	30	1984	-	Y	-	-	2	-	FP	47	12	6.72	0.39	-
EVA 618	ELEC	2	2112	W	SOME	Y	14	-	Y	Y	-	-	0	-	-	53	12	6.60	2.31	Y
EVA 619	ELEC	1	926	W	LITTLE	N	44	-	-	Y	-	-	0	-	-	36	6	7.07	2.06	Y
EVA 620	ELEC	1	1247	W	SOME	Y	25	-	Y	Y	-	-	2	-	-	28	9	6.36	0.37	-
EVA 621	ELEC	1	720	W	LITTLE	N	CANCELLED OUT													
EVA 622	ELEC	2	1892	W	SOME	N	40	-	Y	-	-	-	1	Y	-	69	6	8.09	0.81	-
EVA 623	ELEC	1	2223	W	LITTLE	N	44	-	Y	Y	-	-	1	-	FP	11	13	7.30	0.83	-
EVA 624	ELEC	1	1306	W	LITTLE	Y	12	-	-	Y	-	-	0	Y	-	50	2	8.03	0.55	-
EVA 625	ELEC	1	1056	W	LITTLE	Y	16	1981	-	Y	-	-	2	-	-	41	16	7.97	0.98	-
EVA 626	ELEC	1	988	W	SOME	Y	17	-	-	Y	-	-	1	-	-	28	6	9.22	1.06	-
EVA 627	ELEC	1	1510	W	SOME	Y	18	1984	Y	-	-	-	1	-	FP	56	6	7.64	12.99	-
EVA 628	ELEC	1	1549	W	SOME	Y	25	-	-	Y	-	-	1	-	FP	12	7	5.68	1.83	-
EVA 629	ELEC	1	1363	W	SOME	Y	8	-	-	Y	-	-	1	-	-	78	8	7.14	0.77	Y
EVA 630	ELEC	1	1275	W	SOME	Y	9	-	-	Y	-	-	0	-	-	57	6	7.94	0.41	Y
EVA 631	ELEC	1	1040	W	LITTLE	N	27	-	-	Y	-	-	0	-	FP	41	11	9.03	0.98	Y
EVA 632	ELEC	1	1788	W	LITTLE	Y	20	1981	-	Y	Y	-	0	-	FP	34	4	6.72	1.08	-
EVA 633	ELEC	1	1346	W	SOME	Y	7	-	-	Y	-	-	0	-	-	49	7	7.08	2.09	-
EVA 634	ELEC	2	3224	W	SOME	Y	20	81/84	Y	-	-	-	0	-	-	46	14	6.42	2.32	-
EVA 635	ELEC	1	1518	W	LITTLE	Y	10	-	-	Y	-	-	0	Y	-	59	3	6.49	1.19	Y

APPENDIX A
DATA SUMMARY SCREENING SURVEY (continued)

HOUSE ID#	PRIMARY HEAT	NO. OF STORIES	SIZE (ft^2)	CONSTRUCTION MATERIALS (a)	WEATHERIZED (b)	WALL INSULATION	AGE	REMODEL YEAR	BASEMENT	CRAWLSPACE	SLAB	UFFI (c)	NO. OF SMOKERS	WOODSTOVE	OTHER (d)	HCHO (ppb)	NO_2 (ppb)	H_2O (g/kg)	Rn (pCi/l)	SELECTED FOR FURTHER TESTING
EVA 636	ELEC	1	1547	W	SOME	Y	11	-	-	Y	Y	-	0	-	-	64	2	6.88	1.35	Y
EVA 637	ELEC	1	1260	W	SOME	Y	25	1983	-	Y	-	-	2	-	FP	14	8	7.21	1.08	-
EVA 638	ELEC	1	1076	W	LITTLE	N	51	1980	-	Y	-	-	0	Y	-	40	7	7.88	0.71	-
EVA 639	ELEC	2	2924	W	SOME	Y	45	1984	Y	-	-	-	1	-	-	24	5	6.21	0.24	-
EVA 640	ELEC	1	1778	C	SOME	Y	33	-	Y	Y	-	-	0	-	FP	D	3	5.96	0.57	-
EVA 641	ELEC	1	4152	W	SOME	Y	23	1984	Y	-	Y	-	2	Y	FP	30	3	4.10	3.43	Y
EVA 642	ELEC	1	1267	W	SOME	Y	12	1983	-	Y	-	-	0	-	FP	48	4	8.60	8.00	Y
EVA 643	ELEC	2	1976	W	SOME	Y	28	-	Y	Y	-	-	0	-	FP	17	6	D	1.24	-
EVA 644	ELEC	1	904	W	SOME	N	65	-	Y	Y	-	-	1	Y	-	35	7	7.36	0.83	-
EVA 645	ELEC	1	1066	W	SOME	Y	7	-	-	-	Y	-	0	Y	-	34	6	7.26	3.09	Y
EVA 646	ELEC	2	1784	W&B	SOME	N	36	-	-	Y	Y	-	0	Y	-	45	5	7.04	3.25	Y
EVA 647	ELEC	1	1488	W	SOME	N	29	-	-	Y	-	-	1	-	-	35	4	7.48	0.55	-
EVA 648	ELEC	1	1552	W	LITTLE	Y	16	1984	-	Y	Y	-	2	-	FP	43	6	7.00	0.22	-
EVA 649	ELEC	1	1352	W	LITTLE	N	20	-	-	Y	-	-	3	-	-	31	8	7.94	1.69	Y
EVA 650	ELEC	1	1168	W	LITTLE	Y	25	-	-	Y	-	-	0	-	-	32	4	6.59	2.09	-
EVA 651	ELEC	2	1124	W	SOME	N	30	1984	Y	-	-	-	0	Y	-	23	5	7.54	2.82	Y
EVA 652	ELEC	1	1456	W	SOME	Y	8	1984	-	Y	Y	-	0	-	FP	88	3	6.30	1.25	Y
EVA 653	ELEC	1	945	W	SOME	Y	12	1982	-	Y	-	-	0	-	FP	68	3	7.87	1.19	Y
EVA 654	ELEC	1	1706	W	LITTLE	N	32	-	-	Y	Y	-	3	-	FP	39	7	7.45	0.99	-
EVA 655	ELEC	1	1209	W	SOME	Y	15	1984	-	Y	-	-	0	-	-	54	2	9.09	1.36	-
EVA 656	ELEC	1	1347	W	SOME	Y	13	82/83	-	Y	-	-	0	-	-	41	4	7.25	0.55	-
EVA 657	ELEC	1	936	W	LITTLE	N	41	-	-	Y	-	-	0	-	-	24	4	7.52	1.44	Y
EVA 658	ELEC	1+	2344	W	SOME	Y	15	-	Y	Y	-	-	0	-	-	53	2	7.23	0.74	-
EVA 659					CANCELLED OUT															
EVA 660	ELEC	1	2044	W	LITTLE	N	43	1984	Y	-	-	-	1	Y	-	33	8	6.66	4.23	Y
EVA 661							44		-	Y	-					54	4	6.51	7.7	

(a) CONSTRUCTION MATERIALS

W = wood frame
B = brick
C = concrete block

(b) SUBJECTIVE ESTIMATE OF THE AMOUNT OF EXISTING WEATHERIZATION

- no
- little
- some
- most
- yes

(c) UFFI - UREA FORMALDEHYDE FOAM INSULATION

(d) OTHER TYPES OF COMBUSTION APPLIANCE:

FP = fireplace
PROP = propane
KER = kerosene

M = missing data
D = damaged sampler

APPENDIX B

DETECTION LIMITS FOR LBL PASSIVE SAMPLERS USED IN BPA IN FIELD STUDIES

APPENDIX B

DETECTION LIMITS FOR LBL PASSIVE SAMPLERS USED IN BPA FIELD STUDIES

Passive sampler detection limits are obtained by finding analytical absorbances (HCHO, NO_2) for weight difference (H_2O) which are significantly different from those obtained from representative unexposed sampler blanks. From these values the detection limit for a given exposure duration can be calculated using the sampling rate and correction factors established for each sampler type.

After completion of testing in 1984 and 1985, theoretical detection limits were determined using analysis data from BPA field samples. These detection limits have been selected as the criterion for evaluating and reporting all BPA field study passive sampler results.

The detection limits represent single variates which are significantly different ($P \leq 0.05$) from given populations of field blanks by application of a one-tailed student's t-test (Sokal and Rohlf, 1981).

Formaldehyde Detection Limits:

DETECTION	LIMIT (ppb)	MEAN BLANK	MEAN INVERSE	MEAN
168 Hr	90 Hr	ABSORBANCE	SLOPE	INTERCEPT
11	20	0.0136	4.3099	-.0008

These figures were calculated from the absorbances of 337 field blanks and 65 formaldehyde analyses performed in 1984 and 1985. The limits correspond to a sample concentration of 0.15 μg/cc, an absorbance of 0.036, and a sampling rate of 240 cc/hr.

Nitrogen Dioxide Detection Limits:

DETECTION	LIMIT (ppb)	MEAN BLANK	MEAN INVERSE	MEAN
168 Hr	90 Hr	ABSORBANCE	SLOPE	INTERCEPT
2	4	0.0166	44.159	-.0024

These figures were calculated from the absorbances of 303 field blanks and 47 nitrogen dioxide analyses performed in 1984 and 1985. the limits correspond to a sample concentration of 1.33 m NO_2, an absorbance of 0.030, and a sampling of 60 cc/hr.

Water Vapor Detection Limits:

DETECTION LIMIT (gH_2O/kg AIR)		MEAN BLANK
160 Hr	90 Hr	
0.3	0.5	0.031g

These figures were calculated using the new weight increases of 275 field blanks weighed as part of water vapor analyses during 1984 and 1985. The limits correspond to a sampling rate of 102 cc/hr.

APPENDIX C

WEATHERIZATION SENSITIVITY STUDY

APPENDIX C. BUILDING CHARACTERISTICS
WEATHERIZATION SENSITIVITY STUDY

HOUSE I.D.	YEAR BUILT EST.	# OF STORIES	OCCUPIED LEVELS	PRIMARY SUBSTRUCTURE TYPE	ADDITIONAL SUBSTRUCTURE	HEATING SYSTEM
ECD 26C	1972	2 STORY SPLIT + BASEMENT	0 - 2 1807 ft^2	BASEMENT OCCUPIED 650 ft^2 7.5' CH	VENTED CRAWLSPACE 650 ft^2 4.5' CH ADJOINING GARAGE/UTIL.	ELECTRIC CENTRAL F/A WOOD STOVE IN BASEMENT
ECD 27C	~1900	2 STORY SPLIT + BSMT	0 - 2 2689 ft^2	BASEMENT OCCUPIED 713 ft^2 7' CH	CRAWLSPACE 230 ft^2 14" CH' ADJOINING GARAGE/UTIL. SLAB	WOOD FIRED CENTRAL F/A
ECD 143	~1939	2 STORY + BASEMENT	1 - 2 811 ft^2	BASEMENT UNOCCUPIED 709 ft^2 7' CH	CRAWLSPACE 162 ft^2 6"	ELECT. BSBRD.
ECD 144	~1921	1 1/2 STORY + BASEMENT	1 658 ft^2	BASEMENT UNOCCUPIED 386 ft^2 7.4' CH	CRAWLSPACE 336 ft^2 1.0' CH	ELECT. BSBRD
ECD 145	1975	1 STORY + BASEMENT	0 - 1 1856	BASEMENT OCCUPIED 896 ft^2 7.5' CH	ADJOINING GARAGE SLAB	ELECT CENTRAL F/A WOOD STOVE IN BSMT
ECD 146	~1925	2 STORY + BASEMENT	1 - 2 1092 ft^2	BASEMENT UNOCCUPIED 670 ft^2 7' CH	CRAWLSPACE 43 ft^2 2'4" CH	ELECT. BSBRD. WOOD FURNACE
ECD 147	1892	2 STORY	1 - 2 1103 ft^2	CRAWLSPACE 746 ft^2 1.5' CH	CELLAR 215 ft^2 6.5' CH ON SLAB, SAME LEVEL AS FLOOR 1	
ECD 149	~1944	1 STORY + LOFT & BSMT	1 589 ft^2	BASEMENT UNOCCUPIED 224 ft^2 8.2' CH	CRAWLSPACE 212 ft^2 2.0' CH	WOOD STOVE (PRIMARY) ELECT. BSBRD.
ECD 150	~1934	2 STORY + BASEMENT	1 - 2 1036 ft^2	BASEMENT UNOCCUPIED 242 ft^2 7.0' CH	CRAWLSPACE 426 ft^2 1.0' CH	ELECT. BSBRD + WALL HTR
ECD 151	~1934	2 STORY + BASEMENT	1 - 2 1232 ft^2	BASEMENT UNOCCUPIED 348.2 ft^2 8.4' CH	CRAWLSPACE 285 ft^2 1.5' CH	ELECT. BSBRD. 3 WOOD STOVES
ECD 152	1957	1 STORY	1 736 ft^2	CRAWLSPACE 736 ft^2 2.5' CH		ELECT. BSBRD.
ECD 153	~1975	1 STORY + BASEMENT	0 - 1 2164 ft^2	BASEMENT-OCCUPIED 960 ft^2 7.5' CH	CRAWLSPACE 192 ft^2 4.0' CH	ELECT. CENT. F/A + WOOD STOVE

HOUSE I.D.	YEAR BUILT EST.	# OF STORIES	OCCUPIED LEVELS	PRIMARY SUBSTRUCTURE TYPE	ADDITIONAL SUBSTRUCTURE	HEATING SYSTEM
ESP 003C	~1925	2 STORY + BASEMENT	0 - 2 2172 ft^2	BASEMENT - OCCUPIED 866 ft^2 8.8' CH		CENTRAL F/A GAS? ELECT?
ESP 04C	1978	1 STORY + BASEMENT	0 - 1 1928 ft^2	BASEMENT OCCUPIED 663 ft^2 7.5' CH	ADJACENT GARAGE SLAB	ELECT CENTRAL F/A
ESP 010C	1956	1 STORY + BASEMENT	0 - 1 2402 ft^2	BASEMENT OCCUPIED 1126 ft^2 7.0' CH	CRAWLSPACE 56 ft^2 2' CH ADJOINING GARAGE SLAB	ELECT BSBRD OIL CEN F/A WOOD STOVE
ESP 101	1970	2 STORY + BASEMENT	0 - 2 2225 ft^2	BASEMENT OCCUPIED 1080 ft^2 7.0' CH	ADJOINING GARAGE SLAB	ELECT BSBRD
ESP 103	1961	1 STORY	1 847 ft^2	CRAWLSPACE 847 ft^2 3.75' CH		ELECT BSBRD + WALL HTR
ESP 104	1972	1 1/2 STORY + BASEMENT	0 - 2 1818 ft^2	BASEMENT OCCUPIED 744 ft^2 8' CH	CRAWL/SLAB ADJOINING GARAGE SLAB	ELECT CENT F/A
ESP 108	1955	1 STORY + BASEMENT	0 - 1 3552 ft^2	BASEMENT OCCUPIED 1776 ft^2 8' CH	ADJOINING GARAGE SLAB	ELECT CENT F/A
ESP 109	1976	1 STORY + BASEMENT	0 - 1 1794 ft^2	BASEMENT OCCUPIED 893 ft^2 8' CH	ADJOINING GARAGE SLAB	ELECTRIC CENT F/A
ESP 114	~1958	2 STORY + BASEMENT	1 - 2 2063 ft^2	BASEMENT (UNOCCUPIED) 917 ft^2 7.5' CH	CRAWLSPACE 229 ft^2 5.5' CH ADJOINING GARAGE SLAB	ELECT BSBRD
ESP 115	1979	1 STORY + BASEMENT	0 - 1 2865 ft^2	BASEMENT OCCUPIED 1196 ft^2 7.5' CH	ADJOINING GARAGE SLAB	ELECT CENT F/A
ESP 116	1974	1 STORY + BASEMENT	0 - 1 1828 ft^2	BASEMENT OCCUPIED 922 ft^2 7.5' CH	ADJOINING GARAGE SLAB	ELECT CENT F/A
ESP 117	1972	1 STORY + BASEMENT	1 1406 ft^2	BASEMENT UNOCCUPIED 1138 ft^2 7.5' CH	SLAB ON GRADE (FAM RM) 269 ft^2	ELECT CENT F/A & ELECT BSBRD
ESP 120	~1919	2 STORY + BASEMENT	0 - 2 2382 ft^2	BASEMENT 784 ft^2 7.2' CH		ELECT BSBRD

HOUSE I.D.	YEAR BUILT EST.	# OF STORIES	OCCUPIED LEVELS	PRIMARY SUBSTRUCTURE TYPE	ADDITIONAL SUBSTRUCTURE	HEATING SYSTEM
EVA 505C	~1974	1 STORY	1 1611 ft^2	CRAWLSPACE 1035 ft^2 3.5' CH		ELECT CENT F/A ELECT WALL HTR
EVA 509C	~1940	2 STORY + BASEMENT	1 972 ft^2 (2ND FLOOR NOT INC.)	BASEMENT (UNOCCUPIED) 768 ft^2 8' CH		CENTRAL F/A ELECT WOOD STOVE
EVA 510C	1966	1 STORY	1 1328 ft^2	CRAWLSPACE 1328 ft^2 1.67' CH		ELECT WALL HTR WOOD STOVE
EVA 604	1952	1 STORY	1 849 ft^2	SLAB ON GRADE		ELECT BSBRD
EVA 611	1974	1 STORY + BASEMENT	0 - 1 1840 ft^2	BASEMENT - OCCUPIED 690 ft^2 8'CH	ADJACENT GARAGE SLAB - SAME LEVEL AS BSMT	ELECT CEIL RADIANT
EVA 615	1924	2 STORY + BASEMENT	1 1475 ft^2 (2ND FLOOR NOT INC)	BASEMENT (UNOCCUPIED) 797 ft^2 14' CH	CRAWLSPACE 679 ft^2 2' CH	ELECT CENT F/A
EVA 618	1970	2 STORY SPLIT + BSMT	0 - 2 3049 ft^2	BASEMENT - OCCUPIED 893 ft^2 8'CH	CRAWLSPACE 414 ft^2 5'CH	ELECT CENT F/A
EVA 619	1940	1 STORY	1 945 ft^2	CRAWLSPACE 945 ft^2 2' CH		ELECT CENT F/A
EVA 629	1977	1 STORY	1 1352 ft^2	CRAWLSPACE 598 ft^2 3' CH	ADJACENT GARAGE SLAB	ELECT. BSBRD
EVA 630	1975	1 STORY	1 1392 ft^2	CRAWLSPACE 1372 ft^2 5' CH	ADJACENT GARAGE SLAB	ELECT WALL/SPACE
EVA 631	1957	1 STORY	1 885 ft^2	CRAWLSPACE 885 ft^2 2.5'CH	ADJACENT GARAGE SLAB	ELECT CENT F/A
EVA 635	1975	1 STORY	1 1652 ft^2	CRAWLSPACE 1344 ft^2 3' CH	SLAB ON GRADE (FM.RM) 1308 ft^2 ADJACENT GARAGE SLAB	ELECT CENT F/A

HOUSE I.D.	YEAR BUILT EST.	# OF STORIES	OCCUPIED LEVELS	PRIMARY SUBSTRUCTURE TYPE	ADDITIONAL SUBSTRUCTURE	HEATING SYSTEM
EVA 636	1973	1 STORY	1 1475 ft^2	CRAWLSPACE 1245 ft^2 2' CH	SLAB ON GRADE (REC RM) 221 ft^2 ADJACENT GARAGE SLAB	ELECT. CEIL RADIANT
EVA 641	1961	1 STORY + BASEMENT	1 2428 ft^2	BASEMENT (UNOCCUPIED) 954 ft^2 7.5' CH	SLAB ON GRADE (REC RM) 548 ft^2	ELECT BSBRD
EVA 642	1973	1 STORY	1 1198 ft^2	CRAWLSPACE 1198 ft^2 2.5' CH	ADJACENT GARAGE SLAB	ELECT CIEL RADIANT
EVA 645	1977	1 STORY	1 1040 ft^2	SLAB ON GRADE 1040 ft^2	ADJACENT GARAGE SLAB	ELECT WALL/ SPACE
EVA 646	1949	2 STORY	1-2 2640 ft^2	CRAWLSPACE 1050 ft^2 2.0' CH	SLAB ON GRADE 660 ft^2	ELECT BSBRD WOOD STOVE
EVA 649	1965	1 STORY + BASEMENT	1 1326 ft^2	BASEMENT (UNOC. CELLAR) 1300 ft^2 6' CH		ELECT CENT F/A
EVA 651	~1955	2 STORY + BASEMENT	1 - 2 1136 ft^2	BASEMENT 398 ft^2 7' CH	CRAWLSPACE 451 ft^2 1.3' CH	ELECT BSBRD. ELECT F/A WOOD STOVE
EVA 652	1976	1 STORY	1 1415 ft^2	CRAWLSPACE 1149 ft^2 2' CH	SLAB ON GRADE 266 ft^2	ELECT CEIL. RADIANT WOOD STOVE
EVA 653	1973	1 STORY	1 1080 ft^2	CRAWLSPACE 1080 ft^2 R.5' CH	ADJACENT GARAGE SLAB	ELECT CEIL RADIANT
EVA 657	1943	1 STORY	1 875 ft^2	CRAWLSPACE 875 ft^2 2.5' CH		ELECT WALL SPACE
EVA 660	1942	1 STORY + BASEMENT	1 1322 ft^2	BASEMENT (UNOCCUPIED) 1322 ft^2 7.0' CH	ADJACENT GARAGE SLAB	ELECT BSBRD WOODSTOVE

APPENDIX D

WEATHERIZATION DETAILS AND COSTS

APPENDIX D. Existing Home Study-Improvements Included in House-Doctoring

	ELA (CM^2)	SLA (CM^2/M^2)	ACH 4 PA	WALLS/FLOORS/CEILINGS								WINDOWS			DOORS			FIXTURES				PENETRATIONS/ SERVICE					ACCESS		COMPLETION DATE	COST
				WALL/WALL (JOINT)	WALL/WALL (SEAM)	WALL/FLOOR	WALL/CEILING	WALL/FIREPLACE	CEILING/JOINTS, EXPOSED BEAMS	STAIRS/WALL, FLOOR	SUPPORT/FLOOR, CEILING	TRIM/WALL	ROUGH OPEN/FRAME	GLASS/FRAME	DOOR TRIM/WALL	DOOR ROUGH OPEN/FRAME	DOOR/FRAME	CABINETS/WALL, FLOOR, ETC.	BUILT-INS/FRAMING	SHOWERS, TUBS, ETC.	LIGHTS, HOODS, HEATERS, FANS	ELECT. OUTLETS, SWITCHES	WIRES, CABLES	PIPES, PLUMBING	FLUES, DUCTS, VENTS	HVAC DUCTS, REGISTERS	CRAWL ACCESS	ATTIC ACCESS		
ECD 143					x	x	x		x			x			x		x	x		x	x			x					4/29/85	505.87
INITIAL(*)	187.7	14.97	4.40																											
FINAL(!)	112.6	8.89	2.71																											
ECD 150					x	x	x		x	x	x	x			x					x	x	x		x				x	4/11/85	598.20
INITIAL(*)	71.4	4.79	2.22																											
FINAL(!)	54.5	3.65	1.70																											
EVA 604				x	x	x	x					x	x			x		x	x	x	x	x	x	x	x			x	4/19/85	830.00
INITIAL(*)	44.9	3.67	1.55																											
FINAL(!)	35.3	2.88	1.23																											
EVA 619				x	x	x	x	x				x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	4/22/85	830.00
INITIAL(*)	66.9	4.90	1.91																											
FINAL(!)	55.7	4.09	1.57																											
EVA 646				x	x	x	x	x	x			x	x	x	x	x	x	x	x			x	x	x			x	x	4/11/85	920.00
INITIAL(*)	140.7	3.70	1.66																											
FINAL(!)	92.1	2.42	1.00																											

(*) Test period previous to house-doctoring
(!) PHD

APPENDIX D WEATHERIZATION DETAILS AND COSTS

IDAHO

HOUSE ID	FLOOR AREA (SQ. FT.)	COMPLETION DATE	BPA COST ($)	LBL COST ($)	TOTAL COST ($)	INSULATION LOCATION	INSULATION AREA (SQ. FT.)	INSULATION DESCRIPTION ADDED	INSULATION DESCRIPTION FINAL	STORM WINDOWS NO.	STORM WINDOWS AREA (SQ. FT.)
ECD143	871	4/18/85 (*)	3684.02	650.12	4334.14	WALL	915	R-11	(11)		N/A
						KNEE-WALL	50	R-11	(11)		
						CEILING	582	R-38	(38)		
						FLOOR	1172	R-19	(19)		
ECD144	658	5/8/85 (*)	0 (#)	0 (#)	1498.57	CEILING	430	R-33	(44)		N/A
						CEILING	378	R-30	(30)		
						FLOOR	750	R-19	(19)		
						WALLS	998	R-11	(11)		
						ATTIC KNEE-WALL	277	R-19	(19)		
ECD145	1856	4/23/85 (*)	1731.36	1217.79	2969.15	WALL	60	R-11	(11)		N/A
						CEILING	960	R-23	(38)		
ECD146	1092	5/3/85 (*)	3490.13	640.90	4131.03	CEILING	432	R-27	(38)		
						CEILING	272	R-38	(38)		N/A
						SLOPE CEILINGS	333	R-19	(19)		
						FLOORS	942	R-19	(19)		
						WALLS	1094	R-11	(11)		
						ATTIC KNEEWALL	245	R-19	(19)		
ECD147	1102	5/4/85 (*)	3615.39	713.01	4328.40	CEILINGS	645	R-38	(38)		N/A
						WALLS	1175	R-11	(11)		
						KNEEWALL	76	R-11	(11)		
						FLOOR	783	R-19	(19)		
ECD149	589	4/23/84 (*)	2121.50	374.38	2495.88	FLOOR	301	R-19	(19)	2	5
						WALLS	1168	R-11	(11)		
ECD150	1036	4/2/85 (*)	2180.25	384.75	2565.00	FLOORS	720	R-19	(19)	2	10.5
						WALLS	864	R-11	(11)		
ECD151	1232	5/1/85 (*)	5654.08	1041.44	6695.52	WALLS	1300	R-11	(11)		N/A
						CEILING	544	R-38	(38)		
						SLOPE CEILING	170	R-16	(16)		
						FLOOR	400	R-19	(19)		
ECD152	736	4/18/85 (*)	540.63	95.41	636.04	WALLS	852	R-11	(11)		N/A
ECD153	2164	4/26/85 (*)	1898.24	645.10	2552.34	WALLS	304	R-11	(11)		N/A
						CEILING	960	R-23	(38)		
						CEILING	204	R-27	(38)		
						FLOOR	204	R-19	(19)		

(*) Estimated completion data
(#) Not in BPA service area--owner assumed costs

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

IDAHO

CAULKING							
DESCRIPTION	AREA	# DOORS, WINDOWS	EST. LIN. FT.	DUCT SEALING/ INSULATION	WEATHERSTRIPPING	THERMAL CONVERSION WINDOWS	AREA(SQ.FT)
N/A				N/A	ATTIC ACCESS DOOR 2 DOORS	18	175
N/A				N/A	2 DOORS	2 1 DOOR (METAL INS.)	16.9
YES				N/A	ATTIC ACCESS DOOR 3 DOOR	11	108
N/A				N/A	ATTIC ACCESS DOOR 1 DOORS	10	145
N/A				N/A	2 ATTIC ACCESS DOORS 5 DOORS	12 4 DOORS	141 16
N/A				N/A	2 DOORS	6 1 PATIO	45 73
N/A				N/A	2 DOORS	8	76
N/A				N/A	1 DOOR	10	127
YES	(DOORS & WINDOWS)			N/A	2 DOORS	N/A	--
YES	(DOORS & WINDOWS)			N/A	ATTIC ACCESS DOOR 1 DOOR	6	116

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

IDAHO

HOUSE ID	CRAWLSPACE VENTILATION EXISTING/ADDN. & CHANGES	ATTIC VENTILATION	INSTALL NEW VAPOR BARRIER (FLOOR)	INSTALL VAPOR BARRIER (ATTIC)	CLOCK THERMOSTAT	PIPE INSULATION	OTHER INSTALLATIONS, REPAIRS, ETC.
ECD143	NONE 2.0 ft2	WITH INSUL.(!)	YES	NO	NO	120 ft.	Crawl. Ground Vapor Barrier
ECD144	NONE 1.2 ft2	WITH INSUL.(2.5 ft2)(!)	YES	NO	NO	YES	Crawl. Ground Vapor Barrier
ECD145	N/A - BASEMENT	N/A	NO	NO	YES	N/A	Vent. 2 Fans (1 Bath, 1 Kitchen (&)) Soffit Baffles
ECD146	NONE 1.8 ft2	WITH INSUL.(3.4 ft2)(!)	YES	NO	NO	YES	Crawl. Ground Vapor Barrier, Soffit Baffles
ECD147	NONE 2.3 ft2	WITH INSUL.(1.1 ft2)(!)	YES	NO	NO	YES	Crawl. Ground Vapor Barrier, Vent. 1 Bathroom Fan (&)
ECD149	NONE 1.8 ft2	N/A	YES	NO	NO	NO	Crawl. Ground Vapor Barrier
ECD150	NONE 2.4 ft2	N/A	NO	NO	NO	YES	N/A
ECD151	NONE	2.8 ft2	NO	YES	NO	YES	Vapor Barrier (Attic)
ECD152	PRIOR	N/A	NO	NO	NO	N/A	N/A
ECD153	PRIOR/CLOSED	0.5 ft2	YES	NO	NO	NO	1 Kitchen Fan (&), Soffit Baffles, Crawl. Ground Vapor Barrier

(!) Vent. Added During Attic Insulation
(&) Fan Vented to Outdoors

APPENDIX D WEATHERIZATION DETAILS AND COSTS

SPOKANE

HOUSE ID	FLOOR AREA (SQ. FT.)	COMPLETION DATE	BPA COST ($)	LBL COST ($)	TOTAL COST ($)	INSULATION LOCATION	INSULATION AREA (SQ. FT.)	INSULATION DESCRIPTION ADDED FINAL	STORM WINDOWS NO.	STORM WINDOWS AREA (SQ. FT.)
ESP101	2225	2/25/85	794.00	154.59	948.59	WALL	264	R-11 (11)	1	6
						CEILING	1224	R-20 (38)	FRONT DOOR	
ESP103	847	3/6/85	1384.45	976.27	2360.72	CEILING	880	R-21 (38)	1	40
							880	-- (19)	1	3
ESP104	1818	5/1/85	955.31	168.59	1123.90	WALL	40	R-11 (11)	N/A	
						CEILING	1117	R-20 (38)		
						FLOOR	285			
ESP108	3552	1/31/85 (*)	644.00	1686.80	2330.80	CEILING	1558	R-24 (38)	10	36
ESP109	1794	1/31/85 (*)	391.00	80.26	471.26	WALL	48	R-11 (11)		
						CEILING	1028	R-24 (38)	N/A	
ESP114	2063	2/6/85	1216.76	214.73	1431.49	WALL	976	R-11 (11)	3	9
						CEILING	1200	R-24 (38)		
ESP115	2865	1/14/85 (*)	1140.73	201.31	1342.04	WALL	384	R-11 (11)	N/A	
						CEILING	1657	R-14 (38)		
ESP116	1828	2/25/85	748.27	221.18	969.45	WALL	280	R-11 (11)	4	15
						CEILING	1031	R-16 (38)		
ESP117	1406	2/25/85	2036.53	359.39	2395.92	WALL	1016	R-11 (11)	6	21.5
						CEILING	1476	R-21 (38)	1	40 PATIO
						FLOOR	141			
ESP120	2382	3/6/85	806.91	142.40	949.31	WALL	1551	R-11 (11)	N/A	
						CEILING	352	R-27 (38)		
						KNEEWALL CEILING	112	R-31 (38)		

(*) Estimated completion data

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

SPOKANE

HOUSE ID	CAULKING				DUCT SEALING/ INSULATION	WEATHERSTRIPPING	THERMAL CONVERSION	
	DESCRIPTION	AREA	# DOORS, WINDOWS	EST. LIN. FT.			WINDOWS	AREA(SQ.FT)
ESP101	YES			246	N/A	N/A	N/A	
ESP103	YES			144	N/A	ATTIC ACCESS DOOR	N/A	
ESP104	YES			232	SEAL, INSUL. 36 ft. R-11	ATTIC ACCESS DOOR 2 DOORS - 40 ft2	1	12
ESP108	YES			110	N/A	ATTIC ACCESS DOOR	2	18
ESP109	YES			60	N/A	ATTIC ACCESS DOOR	N/A	
ESP114	YES			160	N/A	ATTIC ACCESS DOOR	N/A	
ESP115	YES			180	N/A	ATTIC ACCESS DOOR	N/A	
ESP116	YES			120	N/A	N/A	N/A	
ESP117	YES			209	SEAL, INSUL. 35 ft. R-11 IN CRAWL	ATTIC ACCESS DOOR CRAWL ACCESS DOOR R-11 DOOR - 20 ft2	N/A	
ESP120	YES			285	N/A	ATTIC ACCESS DOOR	N/A	

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

SPOKANE

HOUSE ID	CRAWLSPACE VENTILATION EXISTING/ADDN. & CHANGES	ATTIC VENTILATION	INSTALL NEW VAPOR BARRIER (FLOOR)	INSTALL VAPOR BARRIER (ATTIC)	CLOCK THERMOSTAT	PIPE INSULATION	OTHER INSTALLATIONS, REPAIRS, ETC.
ESP101	N/A - BASEMENT	N/A	NO	NO	NO	N/A	N/A
ESP103	PRIOR 2.8 ft2	WITH INSUL.(0.6ft2)(!)	YES	NO	NO	140 ft.	Soffit Baffles, Crawl. Ground Vapor Barrier
ESP104	NONE 1.0 ft2	WITH INSUL.(0.3ft2)(!)	YES	NO	NO	16 ft.	Vent Bath Fan (&), Soffit Baffles Crawl. Ground Vapor Barrier
ESP108	N/A - BASEMENT	WITH INSUL. 1.3 ft2 (!) (UPPER) 3.5 ft2 (LOWER)	NO	NO	YES	N/A	Vent 4 Fans (3 Bath, 1 Kitchen) Soffit Baffles
ESP109	N/A - BASEMENT	WITH INSUL. 0.1 ft2 (!) (UPPER) 0.4 ft2 (LOWER)	NO	NO	NO	N/A	Soffit Baffles
ESP114	NONE	N/A	NO	NO	NO	N/A	Vent 1 Fan, Soffit Baffles
ESP115	N/A - BASEMENT	N/A	NO	NO	YES	N/A	Vent 3 Fans (2 Bath, 1 Kitchen) Soffit Baffles
ESP116	N/A - BASEMENT	WITH INSUL. (!)	NO	NO	YES	N/A	1 Fan (&), Soffit Baffles
ESP117	N/A - BASEMENT	N/A	YES	NO	YES	N/A	Vent 3 Fans (2 Bath, 1 Kitchen) Soffit Baffles; Inst. Crawl Access Door; Crawl. Ground Vapor Barrier
ESP120	N/A - BASEMENT	CEILING 0.3 ft2 KNEEWALL 0.7 ft2	NO	NO	NO	N/A	N/A

(!) Vent. Added During Attic Insulation
(&) Fan Vented to Outdoors

APPENDIX D WEATHERIZATION DETAILS AND COSTS

VANCOUVER

HOUSE ID	FLOOR AREA (SQ. FT.)	COMPLETION DATE	BPA COST ($)	LBL COST ($)	TOTAL COST ($)	INSULATION			STORM WINDOWS	
						LOCATION	AREA (SQ. FT.)	DESCRIPTION ADDED FINAL	NO.	AREA (SQ. FT.)
EVA604	849	3/20/85	1482.00	560.88	2042.88	WALL	615	R-11 (11) BLOWN	4	43
						CEILING	892	R-31 (38) GLASS		
EVA611	1840	3/7/85	1898.00	447.58	2435.58	CEILING	1238	R-14 (26)	8	139
						FLOOR	500	R-19 (19)		
EVA615	1475	3/21/85	2967.81	523.73	3491.54	WALL	446	R-11 (11) BATT.	10	137
						CEILING	282	R-31 (38)		
							592	R-38 (38)		
						FLOOR	1350	R-19 (19)		
EVA618	3049	2/21/85	2886.00	1667.95	4553.95	CEILING	912	R-14 (38) ROCKWOOL	14	250
							1176	R-15 (38) ROCKWOOL		
						FLOOR	1176	R-19 (19)		
EVA619	945	3/8/85	1960.00	527.21	2487.21	WALL	837	R-11 (11) BLOWN	9	77
						CEILING	846	R-19 (38) ROCKWOOL		
						FLOOR	926	R-19 (19)		
EVA629	1352	3/8/85	1767.00	734.47	2501.47	CEILING	1363	R-19 (38)	2	12
						FLOOR	1363	R-19 (19)		
EVA630	1392	2/27/85	1612.00	864.28	2476.28	CEILING	1275	R-19 (38)	11	116
						FLOOR	1275	R-19 (19)		
EVA631	885	3/21/85	2398.00	1598.93	3996.93	WALL	725	R-11 (11)	11	135
						CEILING	1040	R-26 (38) ROCKWOOL		
						FLOOR	1040	R-19 (19)		
EVA635	1652	3/13/85	2625.00	500.26	3125.26	CEILING	1518	R-29 (38)	7	150
						FLOOR	1518	R-19 (19)		
EVA636	1475	3/6/85	2276.48	401.73	2678.21	CEILING	1514	R-27 (38) ROCKWOOL	10	152
						FLOOR	1254	R-19 (19)		
EVA641	2428	5/1/85	4386.05	774.01	5160.06	CEILING	1730	R-31	20	385
							676	R-38	3	80
									PATIO	
EVA642	1199	2/7/85	2215.00	710.65	2925.65	CEILING	1267	R-27 (38)		
						FLOOR	1267	R-19 (19)	7	128

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

VANCOUVER

HOUSE ID	CAULKING				DUCT SEALING/ INSULATION	WEATHERSTRIPPING	THERMAL CONVERSION	
	DESCRIPTION	AREA	# DOORS, WINDOWS	EST. LIN. FT.			WINDOWS	AREA(SQ.FT)
EVA604	WINDOWS DOORS	161	10	161	N/A	2 DOORS - 40 ft2	3	78
EVA611	WINDOWS DOORS	219	12	205	N/A	N/A	2 PATIO	80
EVA615	WINDOW	117	12	150	DUCT INSUL. 220 ft. R-11	2 DOORS - 40 ft2	N/A	
EVA618	WINDOWS DOORS	290	16	272	DUCT INSUL. 125 ft. R-11	N/A	2 PATIO	80
EVA619	WINDOWS DOORS	171	11	173	N/A	2 DOORS - 40 ft2	N/A	
EVA629	WINDOWS DOORS	242	11	206	N/A	1 DOOR - 20 ft2	3 2 PATIOS	58 80
EVA630	MISSING DATA							
EVA631	WINDOWS DOORS	195	15	216	DUCT INSUL. 104 ft. R-11	1 DOOR - 20 ft2	N/A	
EVA635	WINDOWS DOORS	190	9	165	N/A	N/A	1 PATIO	40
EVA636	WINDOWS DOORS	212	14	218	N/A	1 DOOR - 20 ft2	1 PATIO	40
EVA641	WINDOWS DOORS	710	32	603	N/A	4 DOORS - 80 ft2	1 PATIO	62
EVA642	WINDOWS DOORS	188	9	164	N/A	N/A	1 PATIO	40

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

VANCOUVER

HOUSE ID	CRAWLSPACE VENTILATION EXISTING/ADDN. & CHANGES	ATTIC VENTILATION	INSTALL NEW VAPOR BARRIER (FLOOR)	INSTALL VAPOR BARRIER (ATTIC)	CLOCK THERMOSTAT	PIPE INSULATION	OTHER INSTALLATIONS, REPAIRS, ETC.
EVA604	N/A - SLAB	WITH INSUL.	NO	NO	NO	N/A	N/A
EVA611	N/A - DAYLIGHT BASE.	WITH INSUL.	NO	NO	NO	N/A	N/A
EVA615	PRIOR	WITH INSUL.	YES	NO	YES	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA618	PRIOR ADD 6 ft2 1ft2 CLOSED	WITH INSUL.	NO	NO	YES	FLOOR INSUL. WRAP PIPES	Repaired Crawl. Ground Vapor Barrier
EVA619	PRIOR 3.9 ft2 CLOSED 1.2 ft2 OPEN	N/A	NO	NO	YES	FLOOR INSUL. WRAP PIPES	Repaired Crawl. Ground Vapor Barrier
EVA629	PRIOR	WITH INSUL.	NO	NO	NO	FLOOR INSUL. WRAP PIPES	Repaired Crawl. Ground Vapor Barrier
EVA630	PRIOR	WITH INSUL.	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA631	PRIOR 5.5 ft2 CLOSED	WITH INSUL.	YES	NO	YES	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA635	PRIOR 3.9 ft2 OPEN	WITH INSUL.	NO	NO	YES	WRAP PIPES	Repaired Crawl. Ground-Vapor Barrier
EVA636	PRIOR 5.8 ft2 OPEN	N/A	NO	NO	NO	FLOOR INSUL. WRAP PIPES	Repaired Crawl. Ground Vapor Barrier
EVA641	N/A - DAYLIGHT BASE.	WITH INSUL.	NO	NO	NO	N/A	N/A
EVA642	PRIOR 3 ft2 OPEN?	WITH INSUL.	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Repaired Crawl. Ground Vapor Barrier

APPENDIX D WEATHERIZATION DETAILS AND COSTS

VANCOUVER

HOUSE ID	FLOOR AREA (SQ. FT.)	COMPLETION DATE	BPA COST ($)	LBL COST ($)	TOTAL COST ($)	INSULATION			STORM WINDOWS	
						LOCATION	AREA (SQ. FT.)	DESCRIPTION ADDED FINAL	NO.	AREA (SQ. FT.)
EVA645	1040	2/27/85	743.00	581.25	1324.25	CEILING	1066	R-23 (38)	6	124
EVA646	2640	4/8/85	2243.00	1181.02	3424.02	CEILING	640	R-34 (38)	15	268
						FLOOR	960	R-19 (19)		
EVA649	1326	6/1/85	4177.04	1488.23	5665.27	WALL	60	R-11 (11) BATT	11	174
							128	(BLOWN)		
						CEILING	884	R-38 (38)		
						FLOOR	1352	R-19 (19)		
EVA651	1136	3/7/85	2543.00	933.52	3476.52	WALL	890	R-11 (11) BLOWN		
						CEILING	464	ROCKWOOL (38)	14	153
						FLOOR	880	R-19 (19)		
EVA652	1415	3/20/85	2001.00	701.89	2702.89	CEILING	1456	R-23 (38)		
						FLOOR	1176	R-19 (19)	6	123
EVA653	1080	3/5/85	1699.00	427.69	2126.69	CEILING	1008	ROCKWOOL R-24 (38)	6	103
						FLOOR	1008	R-19 (19)		
EVA657	875	4/9/85	2213.00	358.43	2571.43	WALL	811	R-11 BLOWN (11)	10	105
						CEILING	943	R-27 CELL. (38)		
						FLOOR	943	-- (19)		
EVA660	1322	2/15/85	2694.00	1237.02	3931.02	WALL	1166	R-11 BLOWN (11)		
						CEILING	1363	R-30 GLASS (38)		

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

VANCOUVER

	CAULKING						THERMAL CONVERSION	
HOUSE ID	DESCRIPTION	AREA	# DOORS, WINDOWS	EST. LIN. FT.	DUCT SEALING/ INSULATION	WEATHERSTRIPPING	WINDOWS	AREA(SQ.FT)
EVA645	WINDOWS DOORS	144	7	127	N/A	2 DOORS - 40 ft2	N/A	
EVA646	WINDOWS DOORS	363	18	323	N/A	3 DOORS - 60 ft2	N/A	
EVA649	WINDOWS DOORS	296	14	257	DUCT INSUL. 135' R-11	N/A	1 PATIO	40
EVA651	WINDOWS DOORS	197	17	231	DUCT INSUL. 15' R-11	2 DOORS - 40 ft2	N/A	
EVA652	WINDOWS DOORS	195	9	168	N/A	1 BUFFER DOOR 20 ft2	1 PATIO	40
EVA653	WINDOWS DOORS	163	8	144	N/A	N/A	1 PATIO	40
EVA657	WINDOWS DOORS	105	11	136	N/A	N/A	N/A	
EVA660	WINDOWS DOORS	257	22	301	N/A	N/A	14 WINDOWS	161 ft2

APPENDIX D WEATHERIZATION DETAILS AND COSTS (continued)

VANCOUVER

HOUSE ID	CRAWLSPACE VENTILATION EXISTING/ADDN. & CHANGES	ATTIC VENTILATION	INSTALL NEW VAPOR BARRIER (FLOOR)	INSTALL VAPOR BARRIER (ATTIC)	CLOCK THERMOSTAT	PIPE INSULATION	OTHER INSTALLATIONS, REPAIRS, ETC.
EVA645	N/A SLAB-ON-GRADE	WITH INSUL.	NO	NO	NO	N/A	N/A
EVA646	PRIOR	WITH INSUL.	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA649	PRIOR 6.3 ft2 OPEN	WITH INSUL.	YES	NO	YES	WRAP PIPES	2 Insulated Doors (40) Crawl. Ground Vapor Barrier
EVA651	NONE	WITH INSUL.	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA652	PRIOR 5.5 ft2 OPEN?	N/A	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA653	PRIOR 5.0 ft2 OPEN?	N/A	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA657	PRIOR CRAWL./BASEMENT	WITH INSUL.	YES	NO	NO	FLOOR INSUL. WRAP PIPES	Crawl. Ground Vapor Barrier
EVA660	N/A	WITH INSUL.	NO	NO	NO	N/A	HOMEOWNER PAID COST DIFFER BETWEEN STORM AND THERMALS

APPENDIX E

TEST PERIOD DATA SUMMARY

APPENDIX E
TEST PERIOD DATA SUMMARY

HOUSE ID	TEST PERIOD CODE	VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
ESP003C	1	16518	0.3	17.2	-3.3	1.5	12	5.5	3.96	2.88		2		8.86	12.24	51.3	23.3	0.6	7.22	1.13	
ESP004C	1	15476	1.1	12.8	-1.47	2	21.5	23.4	4.31	2.68	0.47	3.5	2.5	3.52	11.79	6	30.3	0.13	3.55	0.4	0.41
	2		1.9	13.4	-9.9	1.6	35	5.5	5.83	2.49	0.61	1	1	4.25	9.33	4.1	18.5	0.16	3.6	0.47	
ESP010C	1	17452	0.8	20.3	-1.5	27.6	54.6	19.4	5.01	3.12	0.33	3	2	12.33	12.6	19.7	44.5	0.31	2.63	0.37	0.4
	2		0.5	20.1	-2.9	28.4	26	5.5	4.46	2.58	0.3	3.5	1	12.22	15.19	20.7	42.1	0.45			
	3		1.3	20.2	-5.4	29	48.3	11.5	4.66	3.2	0.31	3	3	9.54	11.03	22.7	34.6	0.32	2.55	0.43	0.45
	4		0.9	20	-1.9	30.5	38.6	5.5	5.05	3.03	0.34	1	1	12.54	13.98	26.2	33.3	0.32			
ECD026C	1	14131	0.2	20.9	-7.7	16.7	34.8	13.5	4.79		0.31	1	1	2.4	9.4	20.2	54.2	0.37	3.32	0.48	0.57
	2		0.3	21.4	-1.3	20.9	57.8	5.5	5.4	3.66	0.34			2.1	5.3	13.4	32.1	0.29			
	3		0.2	19.2	6.6	8.3	58.2	5.5	5.86	4.72	0.42	1	1	1.9	4.1	15.4	35.4	0.28	6.15	0.57	0.86
	MIT1		1.7	20.8	-3.3	14.9	53.1	5.5	5.86	4.25	0.38					16.1	26.1	0.59	3.6		0.74
	MIT3		0.2	20.6	-19.1	17.9	33.2	5.5	4.2	1.78	0.27					19.9	71.6	0.52			
	MIT4		0.3	13	-14	19.6	28.9	11.3	3.45	1.51	0.37					9.2	32.3	0.57			
	MIT5		0.1	16.4	-4.1	14.4	41.4	17.7	4.99	3.54	0.43					26.3	80.5	0.41			
	MIT6		0.1	16	-12.1	19.2	43.2	24.6	4.34	2.04	0.38					48.1	175.2	0.42	3.95	0.23	0.46
	MIT8		0.2	17.2	-6.9	17.5	43.1	12	5.32	3.71	0.43					23.6	58.6	0.5	4.52	0.61	0.95
	MIT10		0.2	17.5	-5.2	15.7	48	14.5	5.35	3.65	0.43					22.1	57.8	0.52			
	MIT11		0.2	17.4	-3.2	13.8	48	5.5	5.82	4.23	0.47					20.7	46.5	0.51			
	MIT12		0.2	16.6	-8.7	16.2	41.9	16.6	5.14	2.61	0.43					23.2	63.3	0.26			
	MIT13		0.6	16.8	-7.4	16	42.4	5.5	4.93	2.78	0.41					16.5	36.7	0.57			
	MIT14		0.5	17	0.5	14	52.2	5.5	5.58	4.68	0.43					20.2	42.1	0.48			
	MIT15		0.2	16.7	0.1	17.3	56.8	5.5	6.11	4.49	0.51					22.3	73.6	0.35	3.53		0.64
	MIT16		0.3	17.9	0.8	14.3	52.5	5.5	6.34	5.12	0.49					16.5	30.8	0.58			
	MIT17		0.2	16.6	-0.2	14.5	47.8	5.5	5.7	4.47	0.48					14	37.1	0.33			
ECD027C	1	19903	1.11	21.2	1.6	45.9	16.3	5.5	4.56	2.71	0.29	1	1	3.7	2.6	23.9	11.6	1.02	8.54	1.04	1.08
	2		1.38	20.7	3.3	53.7	16.5	5.5	5.04	3.58	0.33			2.5	2.5	22.7	14.6	1.31			
	3		1.87	20.4	4.8	52	19.7	5.5	5.61	4.38	0.37	1	1	7.9	2	20.2	7.8	1.3	8.59	1.06	1.09
	4		1.46	19	10.8	39.1	23.5	5.5	5.69	4.61	0.41	1	1	7	1	14.8	21.3	1.22			
	5		2.45	16.9	4.6	46.4	12.5	5.5	5.3	4.15	0.44			7.9	2	12.2	9.1	1.04			
	6		1.86	18.6	10.9	35.3	22.5	5.5	6.03	4.96	0.45	1	1	4.2	1	15.2	19.5	0.85			
	MIT1		1.8	19.9	0.8	46.2	22.1	5.5	8.12	6.42	0.55					17.9	7.2	1.06	8.13	1.09	1.1
ESP101	BSL	16334	0.47	19.15	-5.34	31.6	22.2	5.5	4.99	2.54	0.36	2	1	2.4	16	23.8	19.9	0.15	2.43	0.47	0.82
	PWX		0.71	18.6	-9.4	24.6	25.9	11.5	4.32	1.75	0.32	2	1	4	10	18.1	42.3	0.49	1.9	0.41	0.78
	PO2			20.1	6		31.7	5.5	5.13	3.21	0.35			1.6	5.3			0.42			
	MITP		1.6	18.6	4.1	22.4															
	MIT1		2.2	18	-5.7	26.9	47.9	5.5	5.94	2.69	0.46					17.7	22.4	0.16	1.96	0.42	0.77
ESP103	BSL	6522	1.59	21.05	-4.02	10.8	24.3	17.1	6.23	2.76	0.4	2	2	3.1	12	102.7	14	0.17	9.12	0.93	
	PWX		2.03	24.1	-1.28	0.91	25.8	5.5	6.56	3.17	0.34			2.8	13.1			0.28	4.1	0.57	0.63
	PO2		0.94	21.1	-1.9		19.7	5.5	6.81	4.03	0.43			4.1	9.6	112.1	18.3	0.29			

APPENDIX E
TEST PERIOD DATA SUMMARY (CONT'D.)

HOUSE ID	TEST PERIOD CODE	VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
ESP104	BSL	15606		18.3	-3.76	4.89	14.7	5.5	3.86	2.72	0.29	1	5.5	5.2	12.2	18.7	19	0.32	4.46	0.57	
	PWX		2.25	17.75	7.31	3	15.4	5.5	5.21	4.35	0.41	1	1	2.8	6.3	11.7	11.7	0.55	5.93	0.55	
	PO2		2.45	20.7	4.6		12.3	5.5	5.23	4.28	0.34			2.2	4.2			0.35			
ESP108	BSL	28630	0.79	20.15	-4.02	13.6	33.5	20.4	4.9	3.39	0.33	3	2	6.3	9.2	6.3	31.9	0.33	3.1	0.44	0.45
	PWX		1.86	19.9	-7.85	14.5	23	13.9	4.99	2.56	0.34	1	2.5	8.6	6.4	5.4	47.1	0.34	3.2	0.49	0.5
	PO2		1.1	19.3	-2.3		31	5.5	5.77	3.77	0.41			7.3	11.2			0.27			
	MITP		1.9	20.7	4.2	8.9															
	MIT1		1.6	20.9	-4.5	13	18.9	5.5	5.75	3.43	0.37					6	17.1	0.33	3.08	0.43	0.44
	MIT2		0.7	20.9	-9.5	12.6	23.7	14.1	4.84	2.92	0.31					11.3		0.41			
	MIT3		0.7	20.9	-18.1	13.2	15.9	12.7	4.85	1.72	0.31					53.4	8.7	0.46			
	MIT4		1	20.5	-16.9	13	21.8	24.8	5.34	2	0.35					4.9	31.1	0.45			
	MIT5		0.7	20.3	-10.5	16.3	22.1	5.5	5.57	3.24	0.37					9.6	39.4	0.4			
	MIT6		0.8	20.2	-5.2	14.4	25.6	28.6	5.45	2.11	0.37					22.5	152.5	0.47	3.18	0.57	0.59
	MIT7		1	20.5	-3.9	16.9	23.4	5.5	6.16	3.79	0.4					5	29.1	0.38	2.94		
	MIT8		0.5	20.5	-6.2	12.6	24.3	5.5	6.03	4.1	0.4					4.7	14.1	0.26			
	MIT9		1.2	20.7	-8.3	18.7	25.5	13.5	6.08	4.24	0.39					4.6	24.8	0.35			
	MIT10		2.3	20.6	-6.6	20	22.1	5.5	6.3	3.28	0.41					7.1	36.7	0.25			
	MIT11		1.6	20.3	-3.2	17	22.7	5.5	6.2	3.14	0.41					3.4	14.7	0.31			
	MIT12		1.1	19.7	1.6	14.4	22.1	5.5	6.3	4.32	0.44					3.5	16.2	0.29	2.98	0.44	0.45
	MIT13		1.1	20.1	1.5	20.3	24.6	5.5	6.46	4.98	0.44					8.7	23.3	0.24			
	MIT14		1.2	20.2	-0.6	20.2	26.3	5.5	7.04	5.2	0.47					7.9	19.6	0.28			
	MIT15		2	20	1.7	15.4	21.8	5.5	6.62	4.26	0.45					15.5	14.4	0.33			
ESP109	BSL	14732	2.71	24.55	-3.57	4.05	29.1	11.6	5.07	2.33	0.26	2	1	3.8	13	35.6	32.1	0.24	4.25	0.58	0.66
	PWX		1.86	21.65	-14.5	7.48	25.4	13.7	4.55	1.73	0.28	1	2	3.4	10.2	29	48.3	0.42	3.14	0.45	0.49
	PO2		1.25	22.1	-5.4		36.5	5.5	5.7	3.15	0.34			2.2	10			0.32			
	MIT1		1.1	21.6	-0.5	8.5										30	32.3	0.31	2.76	0.34	0.44
ESP114	BSL	16502	0.25	20.57	-8.39	5.38	21.1	16.6	4.54	2.58	0.3	4		4.5	12	19.9	31.7	0.24	1.99	0.4	
	PWX		0.47	18.8	-6	9.05	21.9	5.5	4.7	3.09	0.34	4	4	3.2	8.7	20.2	23.4	0.28	2.23	0.41	
ESP115	BSL	22773	1.39	23.8	-2.47	1.89	38.2	5.5	4.75	3.22	0.25	3	7	5.1	7.7	31.9	21.9	0.29	4.32	0.55	0.61
	PWX		0.3	24.75	-3.93	2.01	40.4	14.2	5.13	3.21	0.26	1	1	7.4	16.1	26.7	31.9	0.51	3.77	0.48	
	PO2		1.86	23.2	-14.5		31.1	14.5	3.68	1.44	0.2			5.8	9			0.67			
ESP116	PO1	13891	1.1	17.2	-2.31		82.8	22.6	7.12	3.82	0.58			1.6	8.1			0.23			
	BSL		0.43	18.4	-6.45	31.2	43	16.2	5.6	6.73	0.42	2	5	1.9	16.4	45	23.7	0.07	2.14	0.25	
	PWX		1.05	18.15	-5.36	20.9	48.6	5.5	5.92	3.15	0.45	3	3	2.31	6.6	24.6	22.2	0.17	2.34	0.29	
	MITP		3	18.7	4	7.5															
	MIT1		2.5	21.5	-6.7	10.6	60.9	5.5	5.51	2.9	0.34					17.5	26.2	0.45	1.01	0.17	0.22
ESP117	BSL	10681		21.5		11	25.5	15.5	4.43	2.25	0.27	5	1	8.6	19.6	67.4	41.5	1.19	8.92	0.96	
	PWX		0.94	22.75	2	18.6	31.1	5.5	5.48	2.91	0.31	5	2	5.9	13.1	48.6	45.4	0.88	5.97	0.6	
	PO2		0.88	19.3	1.47		28.6	5.5	6.03	3.52	0.43			5.7	1			0.73			
ESP120	BSL	17182	0.71	19.97	-8.95	145	15.3	5.5	6.03	2.16	0.41	1	1	3.4	13.3	15.3	32.4	0.27	3.68	0.67	0.68
	PWL		1.1	20.2	-2.31	161	17.4	5.5	6.4	3.48	0.43	3	2	2.9	12.9	12.7	27.2	0.34	3	0.45	0.46
	RPWL		0.32	20.1	1.54		14.7	11.3	7.13	3.47	0.48			3.5	18.3			0.31			
	PWX		2.03	20	0.6	178	17.1	5.5	7.2	3.95	0.49	1	1	2.2	6.7	7.9	7.6	0.31	2.61	0.39	0.4
	MITP		2	18.5	6.5	127															
	MIT1		1.4	18.3	-6.1	151	25.9	5.5	8.09	5.48	0.61					7	6.5	0.2	3.11	0.38	0.39

APPENDIX E
TEST PERIOD DATA SUMMARY (CONT'D.)

HOUSE ID	TEST PERIOD CODE	VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
ECD143	BSL	8897	0.43	23.8	-1.79	10.4	19.1	5.5	5.34	2.34	0.29	4.5	1	1.2	2.8	23.1		1.26	24.48	2.24	2.39
	PWL		0.94	22	-1.9	7.84	19.1	5.5	5.12	2.78	0.31	1		2	4.5	22.3	8.7	1.08	17.94	1.51	1.62
	PWX		2.45	22.1	4.55	2.99	24.6	5.5	6.96	3.97	0.41			1.5	1	43.7	6.5	0.97	14.97	1.35	1.66
	PHD		0.36	22.15	6.52	2.46	40.4	5.5	8.06	5.16	0.48	1	1	0.7	1	31.2	9.6	0.6	8.98	0.64	
ECD144	BSL	5758	0.83	20.25	-3.86	2.68	21.3	11.2	5.84	3	0.39	1		1.9	10.7	20.6	24.1	0.2	6.08	0.51	
	PWL		0.32	20.4	1.5	4.63	24.1	5.5	6.8	3.48	0.45	1		1.8	10.6	24.8	19.4	0.24	4.86	0.35	
	PWX		0.8	17.75	7.12	2	35.1	5.5	8.15	4.52	0.64	1		1.4	5.1	12.6	8.2	0.14	4.73	0.27	0.29
ECD145	BSL	14400	1.05	20.5	10.5	1.44	30.6	5.5	6.37	4.47	0.42	1		2.9	2.8	18.3	11.8	0.38	4.5	0.35	0.48
	PWX		1.56	21.7	8.08		22.8	5.5	6.73	4.68	0.41	1	1	3	1	39.8	9.6	0.35	2.67	0.25	0.28
ECD146	BSL	8210	0.75	21.15	1.07	2.2	16.6	5.5	6.25	3.4	0.39	1	1	45.2	1	19.3	4.6	1.17	9.18	1.13	
	PWL		0.88	19.9	1.5	1.62	17.4	5.5	5.84	3.86	0.4	1		2.6	1	15.4	3.1	1.07	10.84	1.12	
	PWX		0.74	20.65	7.44	1.08	20.4	5.5	6.13	4.28	0.4	1		1.5	1	23.5	7.3	1	10.6	0.97	
ECD147	BSL	10245	0.58	14.7	-2.9	2.45	9.8	5.5	4.91	3.49	0.47	1		1.6	4.5	21.7	16.2	0.22	5.26	0.56	0.68
	PWL		0.7	17.7	2.48	3.54	8.4	5.5	5.82	4.42	0.46	1	1	2.1	3.2	3.6	7	0.33	5.08	0.5	0.65
	PWX		0.83	17.55	7.66	1.46	9.8	5.5	5.47	4.47	0.43	1	1	2.5	1	14.4	7.8	0.37	5.31	0.42	1.3
ECD149	BSL	5157	0.2	15.85	-2.51	2.04	21	5.5	5.82	3.5	0.52	1		2.12	1	23.2	10.6	0.37	5.35	0.53	0.56
	PWL		0.6	16.4	4.61	0.91	21.8	5.5	6.42	4.23	0.55	1	1	1.6	1	18.1	6.9	0.32	6.93	0.54	
	PWX		1.56		8.08	0.98	15.3	5.5	6.97	4.55		1		1.1	2.1	7	8.2	0.28	7.6	0.52	
ECD150	BSL	6870	1.93	23.55	-4.9	45.2	24.8	5.5	5.99	2.47	0.33	1	1	8	5.4	128.5	20.7	0.61	6.76	1.1	
	PWL		0.72	24.9	4.4	37	37.9	5.5	7.57	4.6	0.38	1	1	9.6	3.3	285.2	18.3	0.71	5.58	0.7	
	PWX		2.24	23.95	5.72	4.84	46.4	5.5	7.57	4.63	0.4	1		10.9	8.4	350.9	11.8	0.75	4.79	0.69	0.85
	PHD		2.02	23.75	3.25	5.36	69.3	12.8	7.38	4.66	0.4	1		7.9	2.6	246.5	8.1	0.43	3.65	0.54	
ECD151	BSL	10010	0.69	15.32	-3.33	0.85	12.6	5.5	4.99	3.22	0.46	1		3	1	42.4	5.9	0.73	7.3	0.8	0.84
	PWL		1.26	17.7	8.61	0.68	12.1	5.5	5.63	4.4	0.44	1	1	3.1	1	21.3	6.1	0.75	4.61	0.44	0.56
	PWX		1	16.57	6.77	0.93	14.2	5.5	6.42	5.29	0.54	1		2.5	1	32.2	8.1	0.39	4.08	0.35	0.39
ECD152	BSL	5888	0.94	16.7	-1.9	1.24	21.5	11.1	5.78	3.24	0.48	1	1	2.2	6.4	74.5	25.7	0.68	5.21	0.38	0.6
	RBSL		0.33	16.95	1.13	2.14	17.8	5.5	6.52	4.35	0.54			1.1	1	38.4	16.3	0.47			
	PWX		0.58	17.85	2.63	1.21	16.3	5.5	6.36	3.96	0.49	2	1	1.8	3.3	43.3	11.8	0.5	3.98	0.34	0.46
ECD153	BSL	15955	1.17	21.95	-0.59	21.2	66.9	5.5	7.88	3.78	0.47	1	1	3.3	1	103.9	16.6	0.21	2	0.23	0.26
	PWX		1.4	23.55	12.1	11.2	88.7	5.5	9.31	5.99	0.51	1	1	2.6	2.4	168.6	12.5	0.15	2.09	0.18	0.21
EVA505C	1	11500		23.8	5.5	1	64.4	5.5	5.74	4.23	0.31	1	1	2.7	13.3			0.33	5.87	0.58	0.59
	2		0.2	22.1	1.3	1.7	53.4	5.5	5.09	4.06	0.3	1	1	1.6	12	12.5	41.6	0.36	6.66	0.67	0.69
	3		0.3	22.7	6.3	1.2	56.7	5.5	5.9	4.96	0.34	1	1	0.7	7.3	8.2	16.2	0.29	6.52	0.49	0.5
	4		0.5	21.7	1.9	0.9	53.8	5.5	5.54	4.55	0.34	1	1	1.6	8.8	5.9	9	0.31	6.57	0.65	
	5		0.3	22.6	9.7	1	59.3	5.5	6.46	5.64	0.37	1	1	1.7	8	9.1	7.6	0.3	6.46	0.52	0.55
EVA509C	2	6150	0.9	16.4	1.2	1.4	8.4	5.5	4.38	3.77	0.37	2	2	4.8	18.4	22.8	46.1	0.37	7.5	0.75	0.76
	3		1	20.1	9.8	1.2	14.5	5.5	6.06	5.07	0.41	2.5	1	4.8	10.6	10.8	17	0.36	8.38	0.94	0.95
	4		1.46	19.4	4.13	0.93	10.3	5.5	6.07	5.37	0.43	1	1	7.5	15.2			0.75			
	5			19.7	7.8		11.1	5.5	6.03	5.03	0.42	1	1	7.2	13.1	7.5	8.4	0.4	9.46	0.97	0.98

APPENDIX E
TEST PERIOD DATA SUMMARY (CONT'D.)

HOUSE ID	TEST PERIOD CODE	VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
EVA510C	1	10624		25	5.5		30.6	5.5	6.58	3.64	0.33	1		2.6	17.2	25.9	38.7	0.17			
	2		1.6	23.8	3.7	1.7	32	5.5	6.63	4.68	0.35	1		2.1	16.9	16.2	48.2	0.18	3.17	0.27	0.49
	3		0.5	23.1	-2.7	1.9	26.1	5.5	6.39	3.23	0.36	1	2	3	14.5	22.4	61.8	0.18	3.22	0.32	0.45
	4		0.26	22.6	6.6	1.8	27.2	5.5	7.37	4.81	0.42		1	1.8	9.6	15.8	21.8	0.17	3.23	0.29	0.41
	5		1.46	24.1	4.1	0.8	24.4	5.5	7.02	5.32	0.37	1	1	3.1	14.2	11.1	8.1	0.33	3.58	0.34	0.47
	6		0.6	24.8	11.9	1	25.8	5.5	7.5	6.42	0.38	1	2	3.1	9.63	11	7.9	0.33	3.77	0.3	0.45
EVA604	BSL	6223	0.79	22.3	5.03	9.29	54.9	5.5	7.16	3.89	0.42	2	1	3.6	11	252.1	40.3	0.11	3.46	0.24	0.26
	PWL		0.53	22	-0.2	11.2	47.8	5.5	6.68	3.07	0.4	2.5	1	4	11.1	435.3	31.9	0.13	3.39	0.26	0.28
	PWX		0.47	21.95	4.46	10.8	50.3	5.5	7.92	4.65	0.47	1	1	3.8	12.1	150.6			3.32	0.23	0.24
	RPWX		1.44	22.05	13.1	5.02	45.8	5.5	7.8	5.84	0.46			7.52	8.9	232.3	12.32	0.35	3.67	0.37	3.56
	PO2		1.03	18.3	9.81		51.6	5.5	7.77	4.25	0.59	1	1	5.9	7.6			0.13	3.25	0.29	0.31
	PHD		0.97	23.65	4.44	7.52	58.8	5.5	8.86	5.05	0.48	2	1	6.9	7.6	294	7.9	0.17	2.88	0.22	0.24
	MITP1		1.4	22.4	-0.1	8															
	MIT1		1	22.2	7.2	9.4	49.4	5.5	7.98	4.38	0.47					426.9	21.4	0.19	3.23	0.26	0.28
	MITP2		1.5	20.5	-1.6	10.2															
	MIT2		0.4	19.8	11.1	12.5	35.5	24.3	6.27	2.79	0.43					290.2	55.8	0.16	3.46	0.23	0.25
EVA611	PO1	14329		21.5	4.5		26.9	5.5	5.38	4.34	0.33			4.6	13.6			0.36	4.03	0.37	0.42
	BSL		1	17.95	-0.37	1.45	27	5.5	5.89	5.23	0.46	1	1	2.7	12.1	13.7	20.5	0.42	4.91	0.46	0.49
	PWX		1.6	18.1	5.01	1.2	24.9	5.5	5.3	4.92	0.41	1	1	3.82	11.1	16.5	15.3		3.7	0.35	1.01
	PO2		0.46	16.1	1.9		24.9	5.5	5.67	6.15	0.49			1.7	10			0.27			
EVA615	BSL	11062	0.83	20.53	2.68		44.9	5.5	5.88	4.71	0.39	1	1	4.7	17.5	145.5	21.3	0.76	11.1	0.84	0.89
	RBSL		0.79	20.13	-2.66	5.55	37.4	13.6	4.84	2.77	0.33	1	1	5.2	18.2	75.1	501.1	0.83	11.48	0.86	0.93
	PWX		1.54	30.4	13.2	1.18	38.6	5.5	5.62	4.97	0.2	1	1	6	14.6	77.3	22.7	0.63	11.9	1	1.03
EVA618	PO1	29320	0.79	19.4	5		55.8	13.5	5.46	4.18	0.38	2	1	4.4	16.9	11.3	18.4	0.29	5.5	0.62	0.64
	BSL		0.98	20.29	1.65	3.83	42.2	5.5	5.15	3.87	0.34	2	2	5.3	18.3	14.2	39.9	0.37	5.8	0.68	0.7
	PWX		0.8	19.04	1.77	1.76	34.8	5.5	4.02	2.95	0.29	2	1	4.9	14.2	12.9	28.5	0.46	4.3	0.53	0.54
EVA619	BSL	7560	0.77	17.45	-1.19	5.01	21.8	5.5	5.06	3.12	0.4	1	1	4.2	17.1	9.9	32.9	0.22	5.25	0.41	
	PWL		0.9	21.3	3.9	3.9	25.2	5.5	5.73	4.32	0.36			4.4	20.9	9.2	31.3		5.31	0.42	
	PWX		0.91	19.15	5.32	1.74	26.6	5.5	6.17	4.47	0.44	1	2	2.5	19	6.1	18.2		4.9	0.35	
	RPWX		1.45	22.95	11.4	0.42	30.3	5.5	6.87	6.51	0.39	1	1	3.2	15.3	6.1	8.5	0.17	4.18	0.28	0.32
	PHD		1.33	22.35	8.63	0.56	35	5.5	6.91	5.65	0.4	1	1	2.5	13.5	5.3	7.4	0.11	4.09	0.34	0.41
EVA629	PO1	10300	0.79	21.9	5		95.1	13.3	5.99	4.11	0.36	1	1	3.3	18.9	46.6	24.4	0.39	4.8	0.4	0.49
	BSL		1.13	21.15	1.12	0.81	65.6	5.5	5.58	3.53	0.35	1	1	3.9	29.1	37.8	38.4	0.53	4.2	0.41	0.66
	PWX		1.26	19.65	7.37	0.22	68	5.5	5.79	4.14	0.4	1	1	2.8	14.5	19.3	11		5.23	0.4	0.74
	RPWX		1.79	24.4	12.2	0.2	60.9	17.7	6.99	6.65	0.36	1	1	15.9	19.4			0.76	4.4	0.35	0.87
EVA630	BSL	10667	0.94	21.7	5.61	0.41	57.4	14.1	6.09	3.81	0.37	1	1	2.9	16.9	21.7	38.1	0.39	6.69	0.58	0.62
	PWX		0.75	20.4	1.55	0.83	46.8	5.5	5.97	3.66	0.39	1	1	3.1	17.3	18.6	40.5	0.43	4.33	0.41	0.45
	PO2		1.07	18.1	2.5		47.1	22.1	6.89	5.02	0.53			2.6	19.5				6.41	0.59	0.63
EVA631	BSL	6863	1.29	22.15	0.04	1.45	20.8	5.5	5.8	3.14	0.34	1	1	11.1	14.3	46	46.1	1.56	4.64	0.43	0.52
	PWL		2.02	24.7	-3.2	1.7	12.4	5.5	5.82	3.89	0.29	1	1	7.2	16.7	24.2	23.6	1.93	5.6	0.58	0.64
	RPWL		0.16	22.2	4.2		15.8	5.5	6.88	4.34	0.41			5.4	17.6				5.36	0.49	0.79
	PWX		2.33	23	5.19	1.19	17.2	5.5	6.57	4.9	0.37	1	1	5.9	12.6	30.6	13.6	1.21	5.36	0.53	0.58
	PO2		1.35	21.7	9.1		15.9	5.5	6.91	5.76	0.42			6.5	11.5			1.32			

APPENDIX E
TEST PERIOD DATA SUMMARY (CONT'D.)

HOUSE ID	TEST PERIOD CODE	VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
EVA635	BSL	12059	0.27	26.9	-0.95	1.42	40.7	5.5	5.31	3.11	0.23	1	1	1.8	5.9	19.4	23.9	0.64	5.05	0.54	0.68
	PWX		0.16	22.3	4.15	1.55	52.8	5.5	6.16	4.64	0.36	1	1	1.4	6.9	18	20.8		6.02	0.54	0.75
	RPWX		0.53	20.9	2.82	0.99	48.7	5.5	5.91	4.38	0.38	2	1	1.6	4.1	18.7	15.1	0.58	3.55	0.32	0.56
EVA636	BSL	12021	2.08	20.2	0.98	1.86	29.8	5.5	4.64	3.35	0.31	2.5	3	1.7	8.7	11.3	26.1	0.22	4.15	0.45	0.47
	PWX		0.98	23	6.51	1.17	27.3	5.5	5.78	4.05	0.32	1	1	1.3	5.5	8.3	16.5		3.93	0.43	0.46
	RPWX		1.44	22.1	10.2	1.49	51	5.5	7.34	6.1	0.44	1	1	0.9	6.7	13.2	2.7	0.18	3.7	0.38	0.42
	PO2		1.6	21.7	5		40.1	5.5	6.02	4.7	0.37			0.6	6.5			0.18	4.62	0.38	0.4
EVA641	PO1	19145	1.22	19	-0.5		30.4	5.5	7.03	4.5	0.51			2.4	11.9				4.51	0.48	0.5
	BSL		1.65	18.65	6.74	2.06	25.9	5.5	6.68	5.72	0.49	1	1	4.7	11.7	77.7	7.9	0.35	5.22	0.47	0.66
	PWX		0.96	21.35	11.3	1.85	27.5	11.3	7.43	5.95	0.46	1	1	4.5	6.1	78.9			4.25	0.47	0.39
EVA642	BSL	9590	0.88	24.15	3.29	1.86	39.3	5.5	6.86	3.78	0.36	1	1	1.5	15.3	31.3	41.2	0.32	5.12	0.48	0.74
	PWX		2.08	24.45	0.12	0.75	43.7	5.5	6.82	4.14	0.35	1	2	1.75	12.78	29.6	20.5	0.22	4.45	0.47	0.74
	PO2		0.16	24.6	4.15		49.6	5.5	7.36	4.4	0.37			6	14.4				4.87	0.47	
EVA645	PO1	7280	0.8	21.3	1.8		31.9	18	5.25	3.62	0.33			4.43	17.92				4.41	0.32	0.41
	BSL			23.35	-0.53	2.25	32.3	5.5	6.06	5.03	0.33	1	1	5.7	18.9	19	40	0.3	4.46	0.42	0.49
	PWX		1.22	19.15	-0.54	3.26	37.9	5.5	6.99	4.42	0.5	1	1	3.09	11.4	25.3	16.3	0.27	4.01	0.32	0.36
	PO2		1.17	21.5	6.2		35.6	5.5	6.86	4.31	0.42			2.4	11.5			0.33	3.62	0.29	0.35
EVA646	BSL	18196	0.75	23.95	-5.83	7.68	34.4	5.5	6.08	3.57	0.32	1	1	3.6	16.5	47.5	40	0.63	3.91	0.54	0.58
	PWX		1.6	14.19	2.52	3.23	26.1	5.5	5.61	4.77	0.55	1	1	2.1	12	10.8	6.8	0.54	3.7	0.44	0.46
	PHD		1.09	20.08	3.98	3.12	41.9	5.5	6.92	5.4	0.47	1	1	3.1	12.8	16.1	7.8	0.47	2.42	0.28	0.29
EVA649	PO1	10608	0.9	23.1	3.9		29.6	5.5	6.33	4.25	0.35			6.8	12.5				10.7	1.17	1.21
	BSL		1.03	23.1	7.29	2.28	31.4	5.5	6.52	4.9	0.36	1	2	5.5	14.7	39.7	15.6	0.92	9.32	0.96	0.99
	PWX			23.7	7.84	1.58	25.2	5.5	6.52	5.07	0.35	1	1	5.6	14.2			1.07	10.33	1.08	1.1
EVA651	BSL	8143	0.75	18.9	2.47	1.99	20.2	5.5	5.67	3.63	0.41	2	1	3.5	16.3	49.4	53.6	1.09	12.06	1.17	1.22
	PWL			20	3.76	1.61	15.5	5.5	6.03	4.97	0.41	2	1	4.6	17.7	32.3	25	1.18	12.9	0.96	1.31
	PWX		1.6	17	5.02	1.78	16	5.5	5.96	4.39	0.49	2	1	3	12.9	28.9	21.3	0.87	9.12	1.08	0.82
EVA652	PO1	10895	0.26	18.3	6.3		54.7	5.5	5.87	5.17	0.44			1.9	11			0.24	5.93	0.54	0.55
	BSL		0.98	18.55	5.5	1.15	45	5.5	5.36	4.32	0.4	1	2	2.9	11.6	13.7			5.33	0.42	0.43
	PWX		2.08	16.9	4.45	1.37	38.2	5.5	5.46	5.15	0.45	2	1	1.8	11	7.5	10.6	0.36	5.29	0.41	0.42
	PO2		1.45	19.3	11.4		62.7	5.5	6.74	6.32	0.48			3.5	10.3			0.32	4.53	0.35	0.42
EVA653	PO1	8208	2.08	20.8	0		67.4	11	6.13	4.15	0.39			2.36	18.4			0.15	3.32	0.37	0.41
	BSL		1.07	22.55	2.46	0.81	65.2	5.5	7.29	4.75	0.42	1	1	2.4	20.9	24.8	24.4		3.18	0.32	0.36
	PWX		1.17	24.1	6.18	0.57	77.5	5.5	7.7	4.2	0.4	1	1	2.3	11.7	33.8	37.4		3.3	0.31	0.47
	RPWX		1.48	25.25	12.2	0.6	94.5	5.5	8.23	6.4	0.4	1	1	4.1	12.8	18.7	17.7	0.21	2.57	0.22	0.47
	PO2		1.53	23.3	13.2		89.5	5.5	7.48	4.94	0.41			2.7	13.4			0.15	3.18	0.24	0.37
EVA657	PO1	7219	0.91	18.3	5.32		14.8	5.5	6.87	4.56	0.52			2.4	14.7				4.24	0.25	1.5
	BSL		1.49	21.85	7.07	1.28	15.9	5.5	6.74	4.67	0.41	1	1	3.4	10.9	14.9	21.8	0.25	4.49	0.34	1.67
	PWL		1.35	20.75	9.12	0.66	15.3	5.5	6.96	5.83	0.45	1	1	3.9	10.8	5.2	10.3	0.29	3.92	0.27	1.5
	PWX		1.41	21.65	12.9	0.77	18.4	5.5	7.67	6.34	0.47	1	1	3.7	11	31.5	16	0.23	3.63	0.21	

APPENDIX E
TEST PERIOD DATA SUMMARY (CONT'D.)

		VOL (ft3)	WIND SPD (m/s)	TEMPERATURE (Deg C)		RADON (pCi/l)	HCHO (ppb)@		H2O VAPOR (g/Kg)		RELATIVE HUMIDITY	CO (ppm)*		NO2 (ppb)#		RSP (ugm-3)		PFT VENT (h-1)	SLA (cm2m-2)	PRED VENT (h-1)	
				AVG. INDOOR	OUTDOOR		AVG. INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR		INDOOR	OUTDOOR	AVG. INDOOR	OUTDOOR	INDOOR	OUTDOOR			UNOCC	OCC
EVA660	P01	10245	0.95	20.7	5.61		51.7	13.9	5.91	3.97	0.38	2.5	1	6.5	19.2	42	35	0.28	5.1	0.38	0.78
	BSL		1.33	20	0.98	12.5	45.7	12.1	6.36	4.29	0.43	4	1	6	20.3	32.5	44	0.41	4.73	0.41	0.78
	PWL		0.93	19.9	-1.31	0.68	41.1	5.5	5.65	3.75	0.39	2	1	7.8	15.4	43.7	48.5	0.41	4.72	0.39	1.38
	PWX			20.25	4.47	0.43	36.8	5.5	6.23	4.22	0.42			8	64.7	34.9	28.9	0.34	4.57	0.37	0.99
	P02			20.9	6.51		24.3	5.5	5.85	4.19	0.37			8.2	15.8				5.17	0.42	1.95

NOTES: (@) Single HCHO measurements below the detection limit of 11 ppb are substituted with 5.5 ppb
(*) CO measurements below the detection limit of 2 ppm are substituted with 1 ppm
(#) Single NO2 measurements below the 2 ppb detection limit are substituted with 1 ppb

Test Period Codes:

MIT[n] Measurement periods during a study of radon mitigation techniques that occurred the following year
P01 = "Passive Only" Test 1. Conducted with only a few instruments before any weatherization.
BSL = "Baseline". Fully instrumented test period before any weatherizations.
RBSL = "Repeat Baseline". Due to the failure of an essential component in "Baseline", the test was repeated.
PWL = "Post Wall Insulation" test peiord. Fully instrumented test after walls were insulated.
RPWL = "Repeat Post Wall Insulation" test period. Repeat of a failed Post Wall test.
PWX = "Post Weatherization". Test period after standard BPA/utility weatherization.
RPWX = "Repeat Post Weatherization". Repeat of a failed Post Weatherization test period.
P02 = "Passive Only" Test 2. Conducted with only a few instruments after standard BPA/utility weatherization.
RP02 = "Repeat Passive Only" Test 2. Repeat of a failed Passive Only test period #2.
PHD = "Post House Doctor". Test period conducted after a House Doctor retrofit.

Control Homes: Since no weatherization was performed on these homes, the letter codes (above) do not apply.
The test periods were instead referred to by number.

APPENDIX F

PILOT STUDY DATA SUMMARY

APPENDIX F

Pilot Study Data Summary

Home	Description	Obvious Pollutant Source	Test Period Average				
			Ventilation[a] (ACH)	HCHO (ppb)	H_2O (g kg^{-1})	NO_2 (ppb)	RSP ($\mu g/m^3$)
Oak 1	2-story frame w/crawl	fireplace	0.57	32	7.07	9	.05
Oak 2	1-story frame w/crawl		0.46	25	7.47	15	--
Oak 3	1-story frame w/crawl-base	remodelling gas range	1.22	22	7.60	21	13.0
Oak 4	2-story frame stucco w/crawl	gas range pipe smoking	0.74	34	8.03	28	21.7
Oak 5	2-story frame stucco w/base	gas range	0.33	25	7.00	38	--
Oak 6	1-story frame stucco w/base., garage & crawl	1981 addition gas range	0.67	38	7.13	9	4.7
Oak 7	3rd floor apt.	basement parking	--	35	7.50	9	--

(a) Calculated heating season infiltration rate from blower door depressurization rates and based on a predictive model by Sherman and Grimsrud (1980).

APPENDIX G

PHASE 2 -- WEATHERIZATION SENSITIVITY

INDOOR CARBON MONOXIDE (CO) CONCENTRATIONS SUMMARY (PPM)

APPENDIX G

PHASE 2 -- WEATHERIZATION SENSITIVITY

INDOOR CARBON MONOXIDE (CO) CONCENTRATIONS SUMMARY

(PPM)

		INITIAL/BASELINE		FINAL/POST WXTN	
GROUP		INSIDE	OUTSIDE	INSIDE	OUTSIDE
		ALL HOMES			
(Complete Sets)	AM	1.41	1.51	1.17	1.10
	ASD	1.17	1.56	0.97	0.68
	Max/Min	5.00/0	7.00/0	5.10/0	3.00/0
	N	35	35	35	35
		CONTROL HOMES			
ALL					
	AM	1.75	1.42	0.58	0.42
	ASD	1.33	0.86	0.66	0.49
	Max/Min	3.50/0	2.50/0.50	1.50/0	1.00/0
	N	6	6	6	6
SPO/CDA					
	AM	1.88	1.38	0.38	0.31
	ASD	1.65	1.03	0.75	0.25
	Max/Min	3.50/0	2.50/0.50	1.50/0	0.50/0
	N	4	4	4	4
VAN					
	AM	1.50	1.50	1.00	1.00
	ASD	0.71	0.71	0.00	0.00
	Max/Min	2.00/1.00	2.00/1.00	1.00/1.00	1.00/1.00
	N	2	2	2	2
		STUDY HOMES			
ALL					
	AM	1.34	1.53	1.30	1.24
	ASD	1.14	1.68	0.99	0.64
	Max/Min	5.00/0	7.00/0	5.10/0	3.00/0
	N	29	29	29	29
SPO/CDA					
	AM	1.95	2.55	1.76	1.50
	ASD	1.48	2.36	1.39	0.91
	Max/Min	5.00/0	7.00/0.5	5.10/0.50	3.00/0
	N	10	10	10	10
VAN					
	AM	1.03	1.00	1.05	1.11
	ASD	0.79	0.85	0.62	0.39
	Max/Min	2.50/0	3.00/0	2.00/0	2.00/0.5
	N	19	19	19	19

APPENDIX H

PHASE 2 -- WEATHERIZATION SENSITIVITY

COMPARISON OF SAMPLES FROM HOMES
WITH AND WITHOUT COMBUSTION APPLIANCES ($\mu g/m^3$)

PHASE 2 -- WEATHERIZATION SENSITIVITY

RESPIRABLE SUSPENDED PARTICLES (RSP) DATA
COMPARISON OF INDOOR SAMPLES
FROM SMOKING AND NON-SMOKING HOMES ($\mu g/m^3$)

INDEX TO APPENDIX H

APPENDIX H
PHASE 2 -- WEATHERIZATION SENSITIVITY
COMPARISON OF SAMPLES FROM HOMES WITH AND WITHOUT COMBUSTION APPLIANCES
($\mu g/m^3$)

	NON-COMBUSTION				COMBUSTION			
	Non-Smoking		All House		Non-Smoking		All House	
	BASELINE	POST WXTN	BASELINE	POST WXTN	BASELINE	POST WXTN	BASELINE	POST WXTN
INDOOR SAMPLES								
Spokane/C d'A Test Homes								
AM	19.08	11.66	51.25	84.94	25.62	22.32	35.54	38.52
GM	18.91	11.39	34.51	29.51	22.32	18.37	28.19	26.37
GSD	1.17	1.30	2.56	4.63	1.86	2.08	2.07	2.45
N	4	4	6	6	8	8	12	12
Vancouver Test Homes								
AM	15.77	18.24	44.48	42.14	35.45	23.88	48.84	31.93
GM	15.03	15.48	22.78	21.43	32.82	22.49	39.49	27.72
GSD	1.38	1.89	2.70	2.87	1.56	1.50	1.91	1.75
N	7	7	9	9	6	6	8	8
All Test Homes								
AM	16.97	15.84	47.19	59.26	29.83	22.99	40.86	35.89
GM	16.34	13.84	26.90	24.36	26.33	20.04	32.36	26.90
GSD	1.34	1.71	2.62	3.40	1.76	1.83	2.01	2.14
N	11	11	15	15	14	14	20	20
OUTDOOR SAMPLES								
Spokane/C d'A Test Homes								
AM	22.86	8.83	21.07	10.90	19.12	24.54	20.39	24.65
GM	22.10	8.69	20.29	10.35	15.29	18.33	16.87	19.01
GSD	1.35	1.22	1.35	1.41	2.17	2.32	2.00	2.17
N	4	4	6	6	8	8	12	12
Vancouver Test Homes								
AM	29.09	24.62	31.36	21.74	40.82	16.56	38.78	18.86
GM	28.20	22.76	30.36	19.61	39.67	15.48	37.19	17.56
GSD	1.31	1.52	1.32	1.60	1.31	1.55	1.38	1.55
N	7	7	9	9	6	6	8	8
All Test Homes								
AM	26.48	18.88	27.24	17.41	28.42	21.12	27.75	22.34
GM	25.58	16.04	25.84	15.19	23.01	17.05	23.14	18.41
GSD	1.32	1.81	1.41	1.69	21.60	1.97	1.99	1.92
N	11	11	15	15	14	14	20	20

APPENDIX H
INDEX TO APPENDIX H

HOUSE AND TEST PERIODS INCLUDED IN RSP TABLES

"S" = SMOKING

"C" = COMBUSTION

Spokane/Coeur d'Alene

			Test Period	
			BASE-LINE	POST WXTN
CONTROL HOMES				
ECD026		"C"	C1	C3
ECD027		"C"	C1	C6
ESP004		"C"	C2	C3
ESP010	"S"	"C"	C2	C5
TEST HOMES				
ECD144			1	3
ECD145	"S"	"C"	1	2
ECD146		"C"	1	3
ECD147			1	3
ECD149		"C"	1	3
ECD150	"S"		1	3
ECD151		"C"	1	3
ECD152		"C"	2	3
ECD153	"S"	"C"	1	2
ESP101		"C"	2	3
ESP103	"S"		2	3
ESP104			2	3
ESP108		"C"	2	3
ESP109		"C"	2	3
ESP114		"C"	2	3
ESP115	"S"	"C'	2	3
ESP117	"S"	"C"	2	3
ESP120			1	4

Vancouver

			Test Period	
			BASE-LINE	POST WXTN
CONTROL HOMES				
EVA505			C3	C6
EVA510		"C"	C4	C7
TEST HOMES				
EVA604	"S"		2	6
EVA611			3	4
EVA615	"S"	"C"	2	4
EVA618			3	4
EVA619			2	4
EVA629	"S"		3	4
EVA630			2	3
EVA631		"C"	2	5
EVA635		"C"	3	4
EVA636			2	3
EVA642		"C"	2	3
EVA645		"C"	3	4
EVA646		"C"	2	3
EVA651		"C"	2	4
EVA653			3	4
EVA657			3	5
EVA660	"S"	"C"	3	5

APPENDIX H

PHASE 2 -- WEATHERIZATION SENSITIVITY RESPIRABLE SUSPENDED PARTICLES (RSP) DATA COMPARISON OF INDOOR SAMPLES FROM SMOKING AND NON-SMOKING HOMES ($\mu g/m^3$)

	SMOKING		NON-SMOKING	
	BASELINE	POST-WXTN	BASELINE	POST-WXTN
Spokane/Coeur d'Alene Test Homes				
AM	75.5	124.5	23.8	18.8
GM	61.5	83.7	21.5	15.7
GSD	2.2	2.7	1.7	1.9
N	6	6	12	12
Vancouver Test Homes				
AM	99.4	90.9	24.9	20.8
GM	69.5	58.9	21.6	18.4
GSD	2.5	2.9	1.7	1.7
N	4	4	13	13
All Test Homes				
AM	85.0	111.1	24.3	19.9
GM	64.6	72.7	21.5	17.0
GSD	2.2	2.7	1.7	1.8
N	10	10	25	25

APPENDIX I

STATISTICAL TECHNIQUES USED IN MODELING

APPENDIX I
STATISTICAL TECHNIQUES USED IN MODELING

In this work, we model the measured pollutant concentration, C, by the calculated concentration $\hat{C}$ $(v_1,v_2,...;p_1.p_2,...)$, where v_i are independent variables and the p_i are parameters. The best values of the parameters are determined by minimization of the sum of the squares of the residuals using a finite-difference Levenberg-Marquardt technique (routine ZXSSQ of the double-precision IMSL). The statistical significance of the result is expressed by the R^2 of the fit and by the F-test. The R^2 is not directly comparable with that obtained from regressions, but is defined in the same manner; as the quotient of the explained sum of squares and the sum of the explained and unexplained sums of squares, i.e.,

$$R^2 = \frac{\sum_{i=1}^{N}(\hat{C}_i - \overline{C})^2}{\sum_{i=1}^{N}(\hat{C}_i - \overline{C})^2 + \sum_{i=1}^{N}(\hat{C}_i - C_i)^2}, \qquad [1]$$

where the $\hat{C}_i$ are the calculated concentrations, the C_i are the measured concentrations, $\overline{C}$ is the mean of the measured concentrations, and N is the number of data points. Values of F that are significant at > .999 and > .9999 are indicated by one and two asterisks, respectively.

APPENDIX J

DATA COLLECTION FORMS

Bonneville Power Administration
Lawrence Berkeley Laboratory

Existing Home Indoor Air Quality Study
Preliminary Site Information

Please gather information on single family detached homes that have already been audited and are awaiting weatherization. Data from approximately 50 homes should be sufficient to represent the housing stock in your service area. All of these homes would preferably be located within a 50 mile diameter circle.

Date:
Utility Name:
Number of homes included in this survey:
General description of the boundaries of the area where these homes are located:

Please provide numbers of homes or a percentage for each of the following categories.

Age

Older than 1950:
1950-1973:
Newer than 1973:

Size

Floor area of conditioned space:
  Less than 1000 ft^2:
  1000 - 2000 ft^2:
  Greater than 2000 ft^2:

Number of floors above grade:
  1:
  2:
  3 or more:

Construction Characteristics

General:
  Wood frame:
  Masonry:
  Other:

Substructure (or combination of):
  Basement:
  Daylight basement:
  Vented crawlspace:
  Unvented crawlspace:
  Slab on grade:

Combustion Appliances

Woodstove:
Unvented space heater:
Vented appliances:

1. Age of house (if known) ______________

2. Number of occupants ______________

3. Number of smokers ___________ (freq. or # of cig.) ___________
____
____

4. Any combustion appliances:

		frequency
kerosene heaters	______________	__________
propane heaters	______________	__________
wood/coal/other stove	______________	__________
gas/propane stove or oven	______________	__________

5. Remodeling:

		Date
New furniture	__________	_______
Carpeting	__________	_______
Cabinetry	__________	_______

Wall Insulation

Date ______________
Type ______________
Urea Form. ___________

6. Complaints about the air (stuffiness, odors, respiratory problems, watery eyes, dampness, etc.)

7. Basement or crawlspace open into the house? ___________

Door or hatch? ___________

8. Problems with humidity or condensation? ______________

Where? ____

When? ____

9. Unusual outdoor activities: farm ______________________

construction __________________

factories ______________________

heavy traffic __________________

After box of samplers are returned:

1. Unusual activities during the week: parties __________________

fumigation ______________

other __________________

Please complete the following information and return with the box of samplers.

Name ______________________________ Date ______________

Address ______________________________

____

Locale: Urban __________ Rural __________

1. Age of house (if known) __________

2. Basic Building Construction:

Exterior Materials ______________________________

____

Interior Materials ______________________________

3. Interior Remodeling: Wall Insulation

	Date		
New furniture ________	______	Date	________
Carpeting ________	______	Type	________
Cabinetry ________	______	Urea Formaldehyde	________
Other ________	______		

4. Type of Substructure:

Crawlspace ______________________ Open Soil? ______________

Soil Covering? ______________

Basement ______________________ Depth below Grade __________ meters

Floor Material ______________

Wall Material ______________

Slab on Grade ______________________

Other ______________________ Describe ______________

5. Combustion Appliances:

		frequency of use
kerosene heaters	________	________
propane heaters	________	________
wood/coal stove	________	________
gas/propane stove or oven	________	________
other	________	________

6. Number of occupants __________

7. Number of smokers __________ Type of smoking and frequency ______________________

____

8. Complaints about the air (stuffiness, odors, respiratory problems, watery eyes, dampness, etc.)

9. Description of bathing or washing facilities: ______________________________

____

10. Problems with humidity or condensation? ______________________________

Where? ______________________________

When? ______________________________

11. Unusual outdoor activities: farm ______________________

construction ______________________

factories ______________________

heavy traffic ______________________

- -

Please make a simple sketch of house floor plan and approximate dimensions (meters) on other side of this page. Indicate where sampler tubes were placed.

survey.b

INSTRUCTIONS FOR AIR POLLUTION SAMPLERS

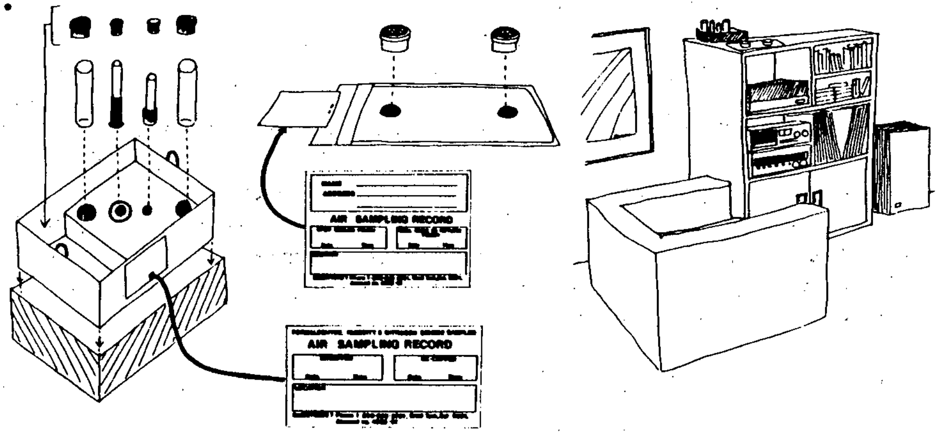
- SAVE THESE INSTRUCTIONS -

Please check the box to be sure it contains the following:

2 capped glass vials (formaldehyde samplers)
1 capped aluminum tube (humidity sampler)
1 capped plastic tube (nitrogen dioxide sampler)
2 plastic/foil pouches: 1 empty
1 with 2 samplers enclosed (radon samplers)

Getting Set Up

- Starting with the 2 glass tubes, remove the tape securing the red caps. Save the caps by placing them in the box. Securely place the tubes, open end up, in the large holes punched in the foam.
- Next, remove the small cap from the aluminum tube and place it, open end up, in the small foam hole circled in red.
- Then uncap the un-taped end of the small clear plastic tube and place it, open end up, in the remaining hole in the foam.
- Make sure all the removed caps stay in the box - you will need them later. Stack and save the two box parts one into the other, as in the drawing.

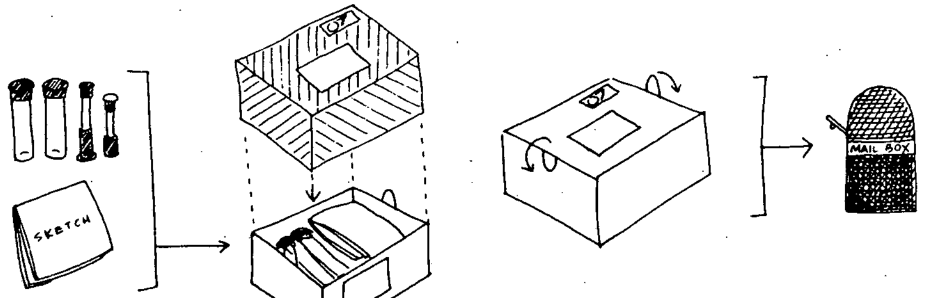


- Record the date and time (a.m. or p.m. from the nearest wall clock) on the form attached to the side of the box. Also jot down the location where the box was placed.
- Placement of the box is important. Try to locate it on a flat surface (bookcase, high table, etc.) high enough above floor level so that children and pets don't interfere with it. It should be in a frequently occupied room (living room or recreation rooms are usually suitable). Try to put it near the center of the room.
- It should be kept away from direct sun, outside walls, open windows, doors to the outside or garage, away from fire places, kerosene or propane heaters. Don't place it in the kitchen or bathrooms. The open tube should be exposed to typical room air and not be covered or located in a confined area (closet, etc.).
- If possible, please indicate on the attached floor plan sketch where the samplers were located. This sketch should be returned to us with the samplers.
- Open the small, sealed Foil Pouch, remove the two cup-like devices from inside and place on the green circles on the larger pouch. This is preferably located near the box of tubes. It is important to keep the cups on the pouch with the green circles since the pouch will be used to mail the cups back to us.
- Write the date and time (a.m. or p.m.) on the card attached to the pouch.

Returning the Tubes

- In approximately one week, one of our staff will call and ask you to recap the tubes. (The yellow "x" cap goes on the clear plastic tube.) Please write the date and time (preferably from the same clock as before) on the form on the box. Place the sketch in the box and secure the box lid by bending the wire hoops over.
- This box is pre-addressed and postage paid and can be dropped in any post office mail box.

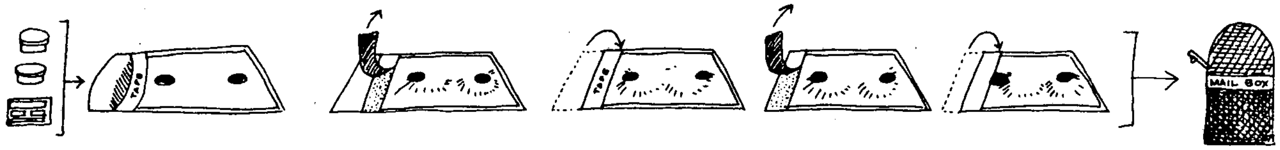
The white cups and green circle pouch will remain at your house for 3 more weeks. Do not place them in the box.



CAP TUBES, COMPLETE FORM ON BOX
ENCLOSE TUBES AND SKETCH .... COVER BOX WITH LID,
BEND WIRE HOOPS DOWN BOX SIDE ..... MAIL

Returning the Cups

- In three weeks, we will call again and ask you to place the white cups in the green-circled pouch. Write the date and time on the attached card and include it in the pouch. Fold the pouch over as shown below and secure with the attached adhesive tape - see drawing (backing must first be removed from the tape to expose the adhesive).
- The pouch is also pre-addressed and postage-paid and can be mailed from any postal mail box.



COMPLETE CARD, ENCLOSE CONTENTS ...... REMOVE 1st BACKING STRIP ...... FOLD TAB OVER, PRESS FIRMLY ...... REMOVE 2nd BACKING STRIP .... FOLD OVER, PRESS FIRMLY .... MAIL

It will take us approximately 1-1/2 weeks to analyze the samplers and determine if your home qualifies for testing in Phase II. You will be notified.

Questions?

Phone:

1-800-638-3753
Brad Turk - Extension 6591
Account # 4888-01
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

WEATHERIZATION SENSITIVITY FORMS

TEMPORARY USE PERMIT

For purposes of this agreement:

1) An "occupant" is a person legally entitled to possession of the premises.

2) An "investigator" is an employee or representative of: The Regents of California, acting through the Lawrence Berkeley Laboratory or the Bonneville Power Administration.

The occupant of the premises located at

____

____________________, grants permission to the investigator to enter such premises from (date) ______________________________ and (date)______________________________, between the hours of ____________________________ and ____________________, for the purpose of conducting research in the field of energy conservation, air infiltration (the airtightness of the house), and indoor air quality.

Any data developed from research conducted on the occupant's premises will be the property of the investigators and may be made available to the public in statistical form, without the occupant's name and address. Upon request, the investigators shall give the occupant a copy of the data. The investigators assume no responsibility to provide information at any particular time or in any specific manner. The occupant understands that the investigators make no warranty, express or implied, that the information provided to the occupant or developed by the research is accurate, complete, or useful.

The occupant understands that the investigators will exercise reasonable care: (1) not to injure the occupant, the occupant's guests, the occupant's property, or the premises; and (2) not to interfere with the occupant's use of the premises except as necessary to undertake the actions provided in this agreement.

Dated this ________________ day of ___________________________, 19_____

By____

Occupant

U.S DEPARTMENT OF ENERGY—BONNEVILLE POWER ADMINISTRATION

INDOOR AIR QUALITY HOUSING STRUCTURE SURVEY

Form Approved
OMB# 1910-1200
Expires 3-31-87

This form will be used for a report pursuant to the Bonneville Project Act (Public Law 75-329). Data is to be collected on a voluntary basis and is considered confidential in accordance with the Privacy Act.

Family Name ____________________ LBL Code ____________

Address ____

Telephone ____________________ Date ____________

GENERAL STRUCTURE CHARACTERISTICS

House Type: ☐ detached ☐ attached ☐ apartment ☐ other (specify) ____________

Size: Area (Occupied Only) ________ ft^2 Total Volume ________ ft^3 (occupied) Age: ________

Structure Materials: ☐ wood ☐ concrete block ☐ poured concrete ☐ other (specify) ________

External Cladding: ☐ wood ☐ stucco ☐ brick ☐ metal ☐ vinyl ☐ concrete ☐ other (specify) ________

Number of floors above substructure: ☐ one ☐ two ☐ three ☐ split ☐ other (specify) ________

Attic: ☐ yes ☐ no Use: ☐ storage ☐ residence ☐ other (specify) ________

Vents: ☐ yes ☐ no Windows: ☐ yes ☐ no

Garage: ☐ detached ☐ attached—one wall borders living space ☐ attached—two walls border living space

Door to living space: ☐ yes ☐ no Area: ________ ft^2

INTERIOR SURFACE MATERIALS

Walls: ____ plaster board, ____ wood, ____ plaster, ____ brick, ____ other (specify) ________

Floors: ____ wood, ____ linoleum, ____ carpet, ____ other (specify) ________

Ceilings: ____ wood, ____ plaster board, ____ plaster, ____ other (specify) ________

ENERGY USE ASPECTS

Heating System: ☐ central forced air ☐ hot water/steam ☐ baseboard ☐ wall/space heater ☐ other (specify) ________

Energy: ☐ gas ☐ oil ☐ electric ☐ solar ☐ other (specify) ________

Heat Exchanger: ☐ central ☐ window ________ flow rate % use: ________ (hrs/day)

Fire Places: ____ number in house ____ number with dampers ____ number with glass doors ____ wood stove

Air Conditioning: ☐ central ☐ windows ☐ heat pump

Infiltration Characteristics: ☐ apparently tight ☐ apparently leaky ☐ uncertain

Weather Stripping: ☐ doors ☐ windows

Exhaust Fans: ☐ kitchen ☐ bathroom ☐ other (specify) ________

Flue Vents: ☐ oven ☐ furnace ☐ other (specify) ________

SUBSTRUCTURE (Complete more than one section, if applicable.)

Basement: floor area ________ ft^2 depth below ground ________ ft. height above ground ________ ft.

Floor Material ☐ open ground ☐ concrete, thickness ________ in. (if known) ☐ other (specify) ________

Floor Finish: ☐ sealant ☐ paint ☐ linoleum ☐ carpet ☐ other (specify) ________

Wall Material: ☐ concrete block ☐ poured concrete ☐ stone ☐ wood ☐ other (specify) ________

Wall Finish: ☐ sealant ☐ paint ☐ plasterboard ☐ other (specify) ________

Doors: ☐ to exterior ☐ to living space ☐ windows ________ ft^2 (total window area)

Drainage: ☐ sump ☐ drain ☐ none ☐ other (specify) ________

Use: ☐ recreation ☐ storage ☐ residence ☐ other (specify): ________

Crawl Space: area ________ ft^2 depth below ground ________ ft. height above ground ________ ft.

Floor Material: ☐ open ground ☐ concrete, thickness ________ in. (if known) ☐ other (specify) ________

Floor Finish: ☐ sealant ☐ paint ☐ none ☐ other (specify) ________

Wall Material: ☐ concrete block ☐ poured concrete, thickness ________ in. (if known) ☐ stone ☐ wood ☐ other (specify) ________

Vents: ☐ yes ☐ no Door (or other opening): ☐ to exterior ☐ to living space

Slab: area ________ ft^2 thickness ________ in. (if known)

Finish: ☐ sealant ☐ linoleum ☐ carpet ☐ wood ☐ other (specify) ________

Other Substructure Type: Describe. ________________________________

BP 847 OCT 1983

U.S. DEPARTMENT OF ENERGY — BONNEVILLE POWER ADMINISTRATION

OMB APPROVAL
1910 - 1200
3-31-87

INDOOR AIR QUALITY DAILY ACTIVITY RECORD

Pursuant to the Bonneville Project Act (PL 75-329), this voluntary information will be kept confidential in accordance with the Privacy Act.

NAME	LBL CODE
ADDRESS	DATE

	3 a.m. - 9 a.m.	9 a.m. - 3 p.m.	3 p.m. - 9 p.m.	9 p.m. - 3 a.m.
NUMBER OF PEOPLE AT HOME				
INDOOR ACTIVITIES				
TOBACCO SMOKING Enter type (cigarettes, cigars, pipe) and number smoked.				
Enter estimated minutes of use for activities below:				
Stove Top Cooking				
Oven Cooking				
EXHAUST FANS VENTED TO OUTDOORS				
Kitchen				
Bathroom				
Other____________				
OTHER ACTIVITIES AND UNUSUAL EVENTS				
Vacuum				
Clothes Dryer				
Fireplace				
Woodstove				
Kerosene Heater				
Windows Opening				
Autos idling in attached garage				
Other: could include house painting, decorating, parties, burnt food, fumigation				
OUTDOOR ACTIVITIES could include heavy traffic, road repair, construction, farm activities).				

Use the back of this form to describe any additional activities which may have affected the indoor air quality of your residence.

BP 848 SEPTEMBER 1984

Log Page ______ of ______

MASTER DATA LOG AND CHECK LIST

Residential Indoor Air Quality Studies

House ID# ______

Occupant Name ______
Address ______

Phone: Home ______
Work ______

Fill in each of the following items as they are completed.

Technician: ______

	Deploy	Remove
Date:		
Arrival Time:		
Departure Time:		

Monitoring period description:
( ) Baseline
( ) Post-wall insulation
( ) Post-Std. Weatherization
( ) Post-House Doctoring
Other ______

Occupant Info: Number of Occupants: ______ Number of Smokers: ______

Continuous Radon Monitor (S/N: ______)

		Deploy	Remove
Replace Filter: (Condition: ______)		( )	
Flow rate (ml/min):			
High voltage (volt):			
CRM operation check.	Time: ______	Count: ______	
	Time: ______	Count: ______	

Comments: ______

Respirable Suspended Particulate Sampler

	Inside (S/N ______)		Outside (S/N ______)	
Location: Pump/Controller				
Filter				
	Deploy	Remove	Deploy	Remove
Time:				
Cyclone condition:				
Filter cassette No.:				
Rotameter reading (mm):				
Vacuum reading (in H2O):				
Air volume (ft3): (Timer Reading)				
Total air volume (ft3) (Elapsed time)				

Comments: ______

Carbon Monoxide Sampler

	Inside (S/N ______)		Outside (S/N ______)	
Location:				
	Deploy	Remove	Deploy	Remove
Time:				
Timer Reading:				
Elapsed Time:				
GE CO Monitor Unit #				
CO Span Gas Value (ppm)				
Zero/span Calibration (✓)		( )		( )
CO readings (ppm): #1				
#2				

Comments: ______

Lawrence Berkeley Laboratory 1/25/85

House ID # ____

Passive Pollutant Samplers

Location:	Out ____	____	____	____	____	Blanks
Deploy Time:	____	____	____	____	____	
Remove Time/Date:	____	____	____	____	____	
Sampler Number:						
Formaldehyde:	____	____	____	____	____	____
	____	____	____	____	____	____
Nitrogen dioxide:	____	____	____	____	____	____
Water vapor:	____	____	____	____	____	____
____:	____	____	____	____	____	____

Comments: ____

Perfluorocarbon Tracer

	A	B	C	D	E	F
Source:						
ID Number	____	____	____	____	____	____
Location:Floor/Room	____	____	____	____	____	____
Item Placed On	____	____	____	____	____	____
Deploy Time:	____	____	____	____	____	____
Remove Time:	____	____	____	____	____	____
Max/min (F)	___/___	___/___	___/___	___/___	___/___	___/___
Sampler:						
ID Number	____	____	____	____	____	____
Location:Floor/Room	____	____	____	____	____	____
Item Placed On	____	____	____	____	____	____
Deploy Time:	____	____	____	____	____	____
Remove Time/Date:	____	____	____	____	____	____

Comments: ____

Energy Signature Monitor (S/N: ____)

Location: ESM ____ Weather Tower ____

Temp. #1 ____ Temp. #2 ____

Data Module # ____

	Deploy	Date 1	Date 2	Date 3	Remove
Check Sensor Values and recorded data	( )	____	____	____	( )

Comments: ____

Nitrogen Dioxide Analyzer

Location:Analyzer ____

Outside Sample ____

Inside Sample ____

	Deploy	Remove
Air Dryer (75% blue) (✓)	( )	( )
Sample Inlet Filter Change (✓)	( )	( )

Calibration:

	1	2	3	1	2	3
Zero air voltage	____	____	____	____	____	____
NO gas cylinder value (ppm)		____			____	

Dilution:

Diluent flow (cc/min)	____	____
Contaminant flow(cc/min)	____	____
Gas mix conc. (ppb)	____	____

	1	2	3	1	2	3
Span gas voltage: NOx	____	____	____	____	____	____
NO	____	____	____	____	____	____
Time:		____			____	

Comments: ____

Homeowner Interaction

	Deploy	Remove
Daily Activities Log (✓)	( )	( )
Schedule next visit (✓)	( )	( )

Comments (sensor location changes, occupant behavior changes, etc): ____

LBL/BPA FAN TEST DATA SHEET

Occupant Name
Address

House ID No.
Blower Door S/N or Descrip.

Technician:
Monitoring Period

Date

BUILDING DIMENSIONS

FIRST FLOOR

Floor Area (ft^2)
Ceiling Height (ft^3)
Volume (ft^3)

SECOND FLOOR

Floor Area (ft^2)
Ceiling Height (ft^3)
Volume (ft^3)

Total Area (ft^2)
Total Volume (ft^3)
Overall Height of Occupied Floors* (ft)

* Include basement or attic only if occupied

ENVIRONMENTAL DATA

Outdoor: Temperature F
Wind Speed MPH

Indoor: Temperature:
Dry Bulb: F
Wet Bulb: F
Relative Humidity: %

Terrain Parameters (Table on back)

Shielding Class
Terrain Class

TEST DATA

	Flow Pressure			
House ΔP (Pascals)	0-120 (Pascals)		120-750 (Pascals)	
	UP	DOWN	UP	DOWN
60/				
55/				
50/				
45/				
40/				
35/				
30/				
25/				
20/				
15/				

Note: Use "down" data for calculations if "up" and "down" are different.

Leakage Coefficients (Table on back)

R = $\left\{ \frac{Lc + Lf}{Lt} \right\}$

X = $\left\{ \frac{Lc - Lf}{Lt} \right\}$

Fan Location
Fan Configuration (11,10,5)
Correlation %
Standard Error
ELA:LBL in^2

LBL Use

SLA
ACH (4 Pa)
ACH (50 Pa)

ENVELOPE CONDITIONS

Fireplace Sealed
Woodstove Sealed
Dryer Vent
Combustion Air
Exhaust Fans
Furnace Flue
Include area (in^2) of other sealed areas
Comments:

IMPORTANT: PILOT LIGHTS: Water Heater
Furnace

Lawrence Berkeley Laboratory 10-14-85

TABLE 1

TERRAIN PARAMETERS

Class	y	a	Description
I	0.10	1.30	Ocean or other body of water with at least 5 km of unrestricted expanse
II	0.15	1.00	Flat terrain with some isolated obstacles (e.g., buildings or trees well separated from each other)
III	0.20	0.85	Rural areas with low buildings, trees, etc.
IV	0.25	0.67	Urban, industrial or forest areas
V	0.35	0.47	Center of large city (e.g. Manhattan)

SHIELDING COEFFICIENTS

Shielding Class	C	Description
I	0.324	No obstructions or local shielding whatsoever
II	0.285	Light local shielding with few obstructions
III	0.240	Moderate local shielding, some obstructions within two house heights
IV	0.185	Heavy shielding, obstructions around
V	0.102	Very heavy shielding, large obstruction surrounding perimeter within two house heights

TABLE OF R AND X VALUES

	House Condition		
House Type	Loose Windows & Doors (R,X)	Average Windows and Doors (R,X)	Tight Windows and Doors (R,X)
1 story (slab)	.3,.3	.4,.4	.5,.5
1 story (basement or crawl)	.5,0	.66,0	.8,0
2 story (slab)	.2,.2	.3,.3	.4,.4
2 story (basement or crawl)	.4,0	.5,0	.6,0

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720