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THE COMPATIBILITY OF ENERGY CONSERVATION AND INDOOR AIR QUALITY

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Table of Contents

EXECUTIVE SUMMARY:

Participation by the Bonneville Power Administration in energy conservation activities, particularly weatherization of existing residences and energy conservation standards for new residences, has raised questions about the effects of these activities on indoor air quality.

The two studies reported here investigated these issues in detail. In the first, a screening survey of pollutant concentrations in 111 unweatherized houses was used to establish baseline pollutant concentrations. Concentrations of formaldehyde, nitrogen dioxide, 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. This region has highly permeable soil that allows unimpeded convective flow of radon-bearing soil gas.

Forty-eight of these houses were studied to evaluate the effects of house weatherization on indoor 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. Changes in concentrations of pollutants and ventilation rates were essentially uncorrelated. Changes in the concentrations of formaldehyde and water vapor as the result of weatherization were small. On the other hand, in houses with crawlspaces, large decreases in indoor radon concentrations were observed due to ventilation that was added to the crawlspace as part of the weatherization process.

The second study reported was an investigation of ventilation and indoor air quality in 61 new houses in the Pacific northwest. Twenty-nine houses built to Model Conservation Standards (MCS) were compared to 32 'Control houses,, i.e., new houses built using conventional practices for the region. The MCS houses met the objective of having significantly reduced air leakage area, yet their total ventilation rate (infiltration plus mechanical ventilation supplied by air-to-air heat exchangers) was the same as the infiltration rate observed in the sample of Control houses. The ventilation in both samples were about 0.3 h^{-1}. Indoor pollutant concentrations were observed to be only poorly correlated

with ventilation rates, an indication that other variables are important. Pollutant measurements made in both samples revealed that 11% of the houses exceeded the BPA mitigation action level of 5 pCi/L for radon concentrations. Thirty percent of the total houses exceed the 100 ppb formaldehyde guideline adopted by many organizations. Indoor pollutant concentrations were seen to vary more between geographic regions than between the two types of house construction.

We conclude from these studies that energy conservation activities in houses do not cause poor indoor air quality and, in some cases, may cause the air quality to improve.

ABSTRACT

Two studies of indoor air quality in residences are described. In the first air quality measurements are reported in 111 unweatherized houses followed by careful observation of changes in ventilation rates and air quality in a subset of forty of the houses that received staged weatherization. A large fraction of the houses sampled in the eastern portion of the state of Washington contained high concentrations of radon gas. The major change in air quality seen in the sample as the result of weatherization was a substantial decrease in radon concentration in houses having crawlspaces. A second study reported compares ventilation and air quality in 62 new residences. Half were built using Model Conservation Standards to promote energy efficiency; the other half were built using conventional techniques for the region. Little difference was seen in ventilation rates in spite of significant design differences. Larger variations in air quality were seen between houses in different regions than between the Control and test houses in the same region. We conclude that changes in housing design and construction to promote energy efficiency are not incompatible with good indoor air quality.

INTRODUCTION

As many of you who do buildings-related work know and understand, it has been difficult to sustain building energy research in the United States during the 1980s. One place where building energy research has continued is in the Pacific northwest states of Washington, Oregon, Idaho, and western Montana, the service territory of the Bonneville Power Administration (BPA). In 1980 Congress passed the Pacific Northwest Power Planning Act that required the BPA Administrator to seek wholesale energy sources first from conservation and renewable sources before building any additional capacity. That act has been the cause of significant amounts of research in this decade. With the U.S. Department of Energy (DOE) and other federal agencies reducing their efforts in building energy research, the BPA activities allowed some work to continue, other work to begin.

Our program at Lawrence Berkeley Laboratory (LBL) has studied many topics with the support of BPA and DOE. The four **major** projects were: (1) examination of the effects of weatherization on indoor air quality in existing residences, (2) indoor air quality and ventilation studies in 40 commercial office buildings in the region, (3) examination of indoor air quality in new houses built to energy-efficient Model Conservation Standards (MCS), and (4) mitigation of problem situations discovered in these studies. This paper will focus on specific interactions between residential conservation activities and indoor air quality (the first and third items in the list). In particular, it will discuss comparisons in indoor air quality between houses before and after weatherization activities that improve energy efficiency; and comparisons between two groups of houses, a group of houses built to new, energy-efficient standards and houses built following conventional techniques. Expanded reports of these studies are available from LBL (Turk *et al.*, 1987; Turk *et al.*, 1988).

WEATHERIZATION AND INDOOR AIR QUALITY

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. Plausibility arguments support the contention that reducing ventilation in buildings, an important component of most conservation activities, causes a deterioration of indoor air quality. 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.* (1988).

The studies demonstrated that it was difficult to attribute changes in pollutant concentrations to weatherization activities. The two reports that did demonstrate effects (Nagda *et al.* (1985), and Traynor *et al.* (1988)) were restricted to laboratory-type demonstrations that are difficult to generalize. The study reported in this paper was initiated to address the following objectives:

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

2) study the effect of weatherization on indoor pollutant levels.

Screening Survey

The study consisted of a screening survey of indoor air quality in 111 unweatherized houses followed by staged weatherization in 40 of these 111 structures. Study sites were located in two of the three major climate areas of the BPA region shown in Figure 1. Houses in Portland and Vancouver, WA are found in the mild, coastal region while houses in Spokane and Coeur d'Alene, Idaho are located in located in the high plateau desert region east of the Cascade Mountains.

Measurement Techniques

Passive samplers to measure concentrations nitrogen dioxide, water vapor, formaldehyde, and radon were mailed to homeowners who put them in place using the shipping box as the sampler holder. Extensive telephoning was required to assure that instructions were followed. A discussion of instrumentation used in the studies is included in Appendix A.

Survey Results

The screening survey results indicate that indoor concentrations of nitrogen dioxide (geometric mean of 5 ppb), formaldehyde (geometric mean of 37 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 houses in the Spokane River Valley/Rathdrum Prairie of Washington and northern Idaho. The geometric mean concentration for 43 houses in that area was 4.4 pCi/L, compared with other regional and national studies that range from geometric means of 0.8 to 1.0 pCi/L. The high indoor radon levels found in the Valley/Prairie are due to the convective flow of radon-bearing soil gas from a highly permeable soil into the houses.

Weatherization Study

Forty-eight houses from the screening survey were chosen to participate in the weatherization sensitivity phase of the study. Eight of the houses remained unweatherized during the study and acted as control structures; monthly measurements of pollutant concentrations were made in these houses to track the impact of non-weatherization factors on pollutant concentrations. The remaining houses underwent a variety of staged weatherization retrofits: all 40 houses received the standard BPA weatherization package, 14 houses also received wall insulation, while five of the forty houses also received house doctoring.

Measurement Techniques

Building and pollutant measurements were obtained using passive samplers where possible, real-time instrumentation where necessary. Figure 4 shows the measurement configuration for the passive samplers. (A complete list of the instrumentation used is presented as Table A-1 of Appendix A.)

Changes Observed

Air leakage

Figure 5 shows the average changes in specific leakage area that were observed as a result of weatherization. (*Specific Leakage Area* is the leakage area of a house measured using a blower door divided by the floor area of the house. When the leakage area is measured in cm^2 and the floor area is measured in m^2, the specific leakage area for U.S. houses is a number in the range of one to ten.) Spokane/Coeur d'Alene houses were more tightly sealed against air leakage, both before (geometric mean specific leakage area of 4.9 cm^2/m^2) and after weatherization (geometric mean of 4.1 cm^2/m^2) than the Vancouver area houses (geometric mean of 5.3 and 4.9 cm^2/m^2, respectively). BPA's standard weatherization program reduced the specific leakage area of the 40 weatherized structures approximately 12.5%. The reduction due to wall insulation (6%) was not statistically significant. House doctoring resulted in an additional reduction in leakage area of 26%.

Ventilation rates

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 reflects a fundamental difference between the two measurement procedures (Sherman, 1988). The difference creates an ambiguity in interpreting individual house ventilation rates. However, the changes seen when normalized to a standard environmental condition will scale with the leakage area of the house. Therefore, we use the change in the leakage area of the house as a measure of the change in the ventilation produced by weatherization. (see Figure 6)

Pollutant concentrations

Comparisons of changing pollutant concentrations with changing ventilation rates generally show little correlation between the two. Factors other than ventilation, including pollutant source strengths, occupant effects, and environmental conditions are more important in influencing indoor pollutant levels.

Changes in pollutant concentrations, while not correlated with changes in ventilation, nonetheless did occur. As shown in Figure 7, measured data from this study showed increases of 11% in water vapor concentrations, 1% in formaldehyde concentrations, and reductions of 6% in NO_2 and 43% in radon concentrations 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.

Simplified models were developed to evaluate the impact of weatherization on indoor air pollutants. The models were used to recalculate radon, water vapor, and formaldehyde concentrations from before and after weatherization to corrected standard conditions. The concentrations adjusted to standard conditions show an increase of 8% in post-weatherization water vapor concentration relative to pre-weatherization conditions; a decrease of 3% in formaldehyde concentrations, and a decrease of 33% in radon concentrations. Only the changes in the radon concentrations are statistically significant. Figure 8 separates the radon results by substructure type. The figure shows that only in crawlspace houses, where ventilation is added to crawlspaces during weatherization, were the indoor radon levels significantly reduced. Radon levels in houses with other substructure types may have decreased also, but the changes are not statistically significant.

The impact of weatherization on indoor air quality is rather modest with the exception of its impact on radon concentrations. In a house with a crawl space, the standard BPA weatherization package improves indoor air quality by reducing radon concentrations.

Weatherization Summary

* Existing house indoor pollutant concentrations were low except for radon concentrations in the Spokane area.

* Standard weatherization reduced the specific leakage area and therefore the ventilation in these houses by 12%.

* A poor correlation was seen between ventilation changes and changes in pollutant concentrations.

* Weatherization had a modest effect on pollutant concentrations other than radon. Radon concentrations decreased in crawl space houses due to weatherization. Reductions in houses with other foundation types were seen but were not statistically significant.

INDOOR AIR QUALITY IN NEW ENERGY-EFFICIENT RESIDENCES

Model Conservation Standards (MCS) in the Pacific Northwest for the construction of new energy-efficient houses include specifications that would lead to reduced air leakage and infiltration. (The specifications also call for installation and operation of air-to-air heat exchangers to raise the ventilation above 0.5 h^{-1}.) When this program was planned concern was expressed about the impact of the new energy-efficiency standards on indoor air quality.

A search of the literature showed that while several small studies of this issue had been reported (Berk *et al.*,1980; Dumont, 1986; Figley, 1985; Figley, 1986; Fleischer *et al.*, 1982; Hollowell *et al.*, 1980; Lipschutz *et al.*, 1981; Nero *et al.*, 1983; Traynor *et al.*, 1985) the results were inconclusive because of: (A) a lack of ventilation measurements; (B) a lack of an adequate group of control houses used as a comparison sample; (C) inadequate justification of the houses as "energy-efficient"; (D) attention to a single pollutant; or (E) an insufficient number of houses for a statistical evaluation. In the study described here twenty-nine MCS houses were monitored along with 32 new houses, built according to standard construction practices, that served as controls. The goals of the study were to compare pollutant concentrations and ventilation rates in the two groups of houses.

Measurement Techniques

Passive samplers were used for monitoring nitrogen dioxide, formaldehyde, water vapor, radon concentrations and to measure the concentration of perfluorocarbons used as a tracer gas to measure ventilation rates. The set used in each house is shown in Figure 4. Passive samplers are discussed further in Appendix A.

Measurement Results

Ventilation

The average leakage area of the envelope measured by fan pressurization for the MCS houses was approximately 46% lower than for the Control houses (Figure 9). However, measured ventilation rates, determined with a passive perfluorocarbon tracer (PFT) technique were virtually identical for both groups of houses, with a geometric mean of 0.30 h^{-1} for the MCS houses and 0.26 h^{-1} for the Control houses, both lower than the design target of 0.6 h^{-1}. From the data, it is estimated that the AAHX was responsible for providing an average of 0.2 h^{-1} of additional ventilation to the natural ventilation in the MCS houses. Figure 10 shows results of both seven-day PFT measurements (to coincide with the week-long passive sampler measurements) and the extended two-month measurements that were concurrent with measurements of radon concentration.

Pollutant concentrations

In general, indoor concentrations of radon and formaldehyde exhibited greater dependence on the region in which a house was located than on the construction practices used in its construction (Figures 11 and 12). Differences in radon levels between MCS and Control houses by region or for all houses are not considered significant. Radon concentrations were higher in houses in the Spokane/Coeur d'Alene region (geometric mean 2.6 pCi/L) due to the local highly-permeable gravelly soils. Portland area houses had a geometric mean of 1.1 pCi/L. Eleven percent of all houses in this study exceeded the BPA mitigation action level of 5 pCi/L while 16% were above the EPA guideline of 4 pCi/L. Eighteen of the 61 houses (30%) had indoor formaldehyde levels above 100 ppb, a frequently cited guideline (Figure 12). The combined MCS and control houses in the Portland area have a geometric mean formaldehyde concentration of 93 ppb, while Spokane area houses had a geometric mean of 60 ppb. The difference was much greater than that between all MCS and Control houses (82 vs. 72 ppb). The regional difference is likely a result of different emission characteristics of pressed-wood products used in the two areas.

Water vapor concentrations were surprisingly similar both between groups of houses and between regions, even though outdoor concentrations were considerably higher in the Portland area (Figure 13). Average indoor concentrations ranged from a low of 6.29 g/Kg in Spokane area MCS houses to a high of 6.81 g/Kg in Portland area MCS houses. Control house group averages were between these extremes. Water vapor levels in Control house bedrooms were significantly higher than in other locations in these houses. There were no significant spatial differences in the water vapor concentrations in the MCS houses, presumably due to the more uniform distribution of ventilation air by the AAHX.

Summary

To summarize:

* MCS houses were 46% tighter than houses built using conventional techniques in this region. The addition of an AAHX boosted the ventilation in the MCS houses to values equivalent to the conventional control houses, about 0.3 h^{-1}.

* Indoor pollutant concentrations were similar for the two groups of houses. Larger differences were seen between houses in different regions than

between control and MCS houses.

* Bedrooms most frequently exhibited high water vapor and formaldehyde concentrations although the effect is less pronounced in the MCS houses, possibly due to mechanical ventilation.

* Little correlation was seen between ventilation rate and pollutant concentrations.

* High radon concentrations were seen in some houses built in the Spokane River Valley

SUMMARY

This work and work that we and others have done in other areas in this research field leads us to the following generalizations.

A. Air pollution is a buildings problem. The major exposure to air pollutants occurs within buildings.

B. The quality of air in buildings is dominated by the sources that are present. In some cases these are small, but the volume of air they pollute (the building volume) is also small when compared to the volume of the atmosphere. Therefore, pollutant concentrations can and do become large within buildings. This, coupled with the large time people spend in buildings, leads to the large exposures mentioned above.

C. Ventilation is currently the best general control strategy for indoor pollution within a building. If we know what the pollutant sources are it is better to restrict the sources than to use ventilation for indoor air quality control. However, in many cases we do not yet know what the sources are nor do we understand how those we can identify behave in all situations. Since outdoor ventilation air dilutes indoor air it reduces the indoor concentrations of all pollutants, those that are known and those that are unknown. Note that this statement carries the assumption that outdoor air is cleaner than that found indoors, an assumption that is sometimes not true.

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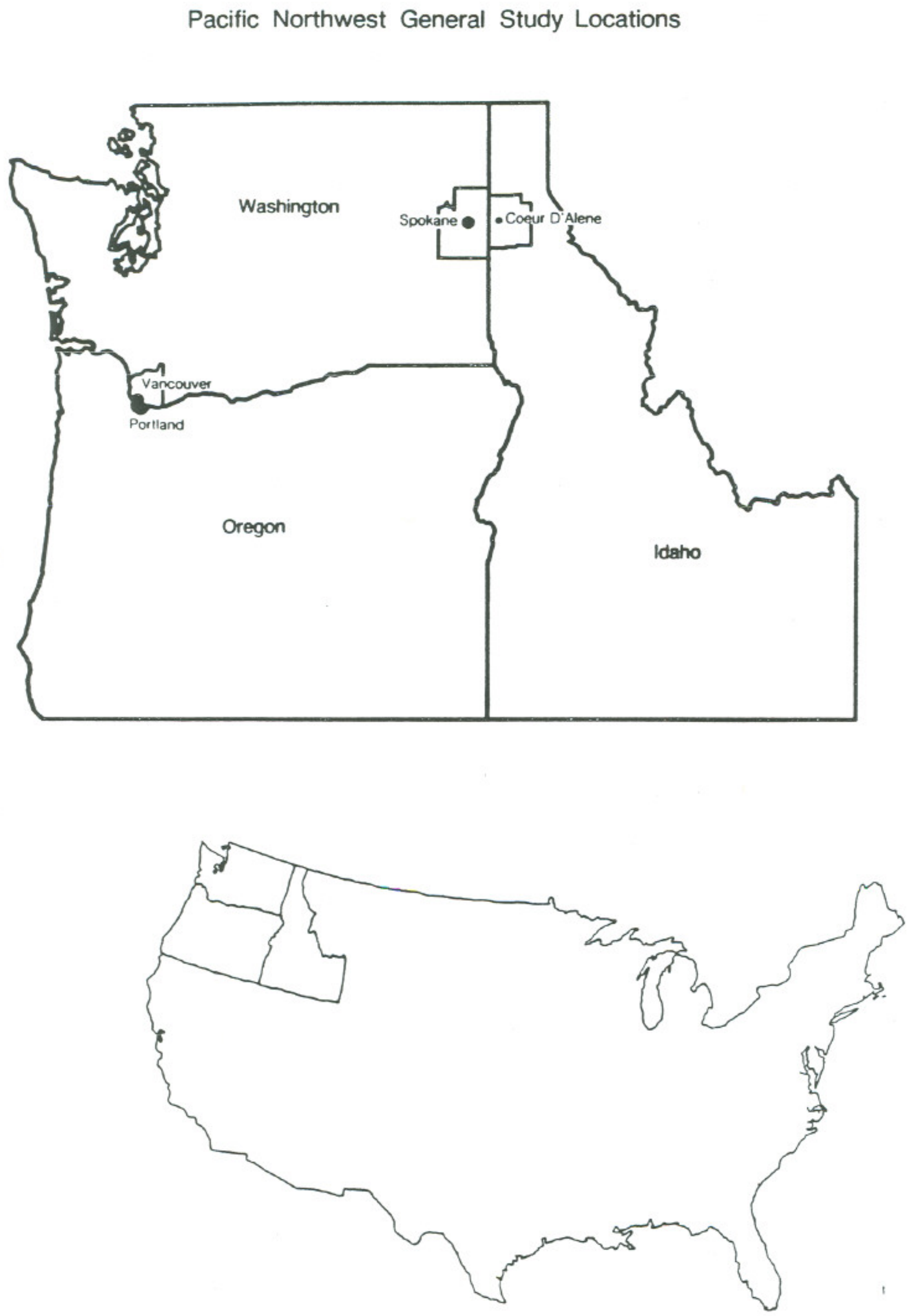

Figure 1. Studies reported here were made in the three-state region of the Pacific northwest shown on this figure. The Portland, OR -- Vancouver, WA area has a mild, coastal climate (2600 deg. C days) while the Spokane, Coeur d'Alene area has a climate associated with a high plateau desert (3800 deg. C days).

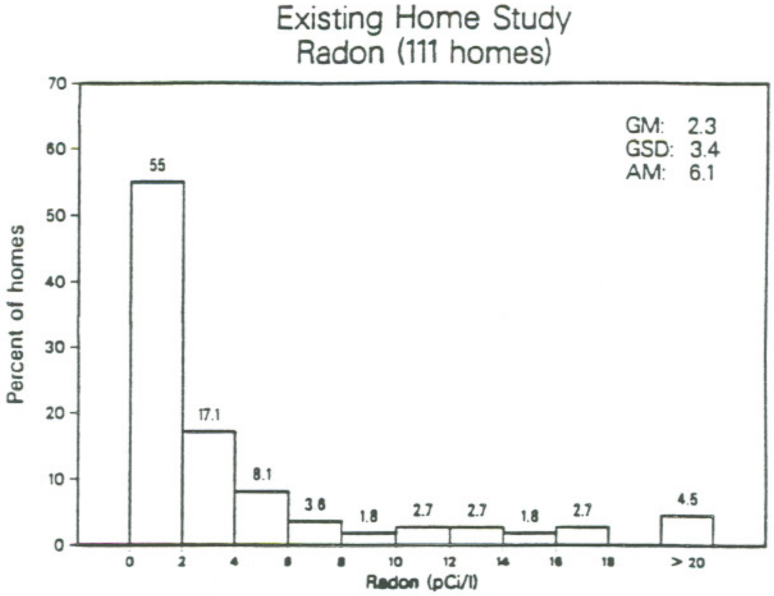

Figure 2. Histogram of indoor radon concentrations measured at 111 homes during the screening phase. Data from 13 of the Spokane/Coeur d'Alene homes are from the 7- to 10-day weatherization period continuous radon measurement. Data for three other homes from this same area are based on 30-minute CRM monitoring. All other data are from a 21- to 35-day alpha track detector measurement during October through December.

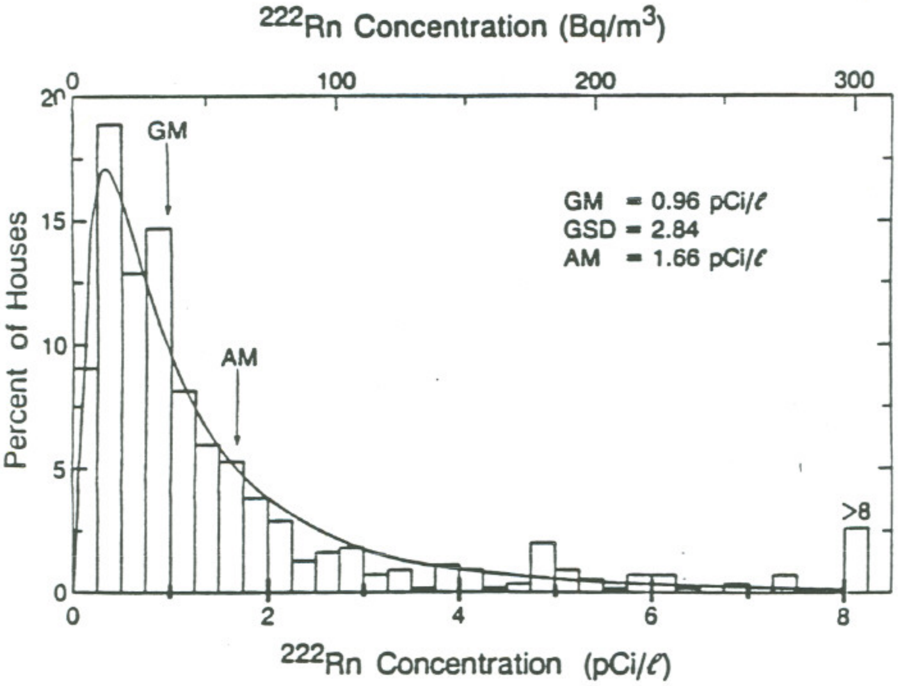

Figure 3. Radon distribution for 552 U.S. Homes as summarized by Nero et al., 1986. Data are distributed lognormally with a geometric mean of 0.96 pCi/L.

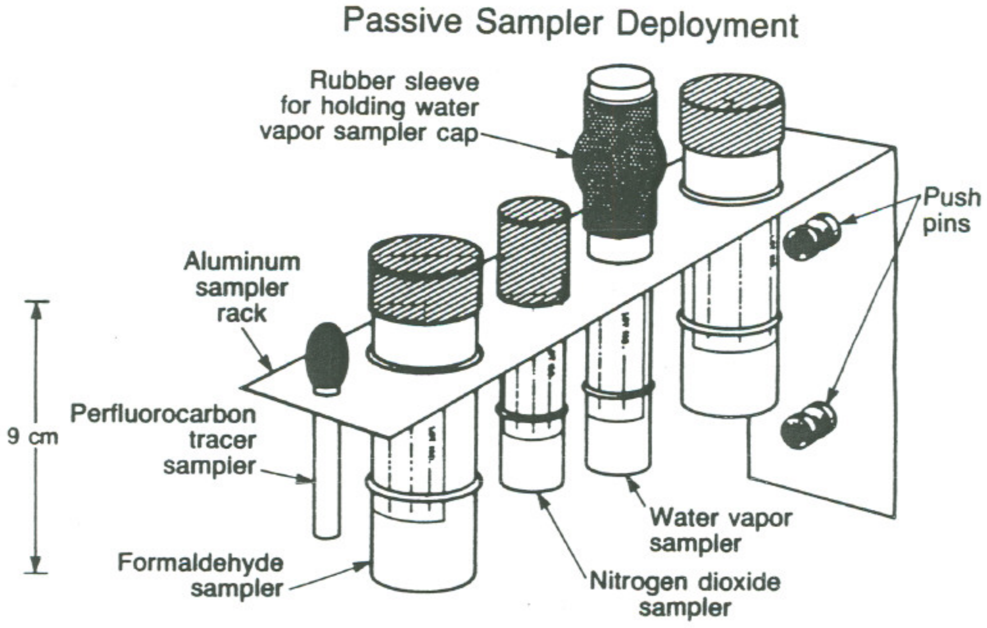

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Figure 4. Deployment method for passive samplers. Samplers were exposed for seven to ten days. See Appendix A for further details about the samplers.

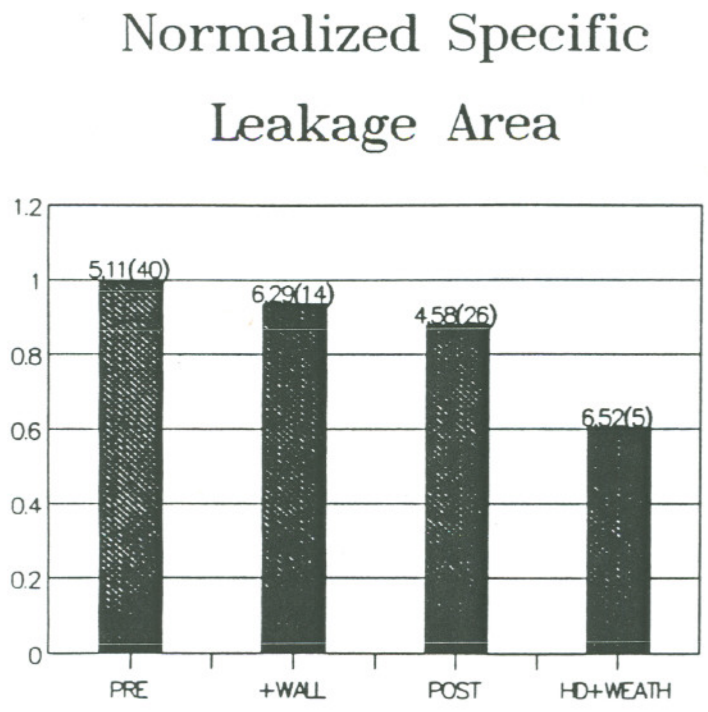


Figure 5. Ratio of specific leakage area after weatherization to that measured before weatherization.

Weatherization

IN HOUSES WITHOUT MECHANICAL VENTILATION, THE INFILTRATION IS GIVEN BY A FUNCTION OF THE FORM:

$$\mathrm{Inf} = (SLA)\left[B(\Delta T) + C\left(v^2\right)\right]^{1/2}$$

WHERE:

Inf is the Infiltration,

SLA is the Specific Leakage Area,

Δ T is the indoor–outdoor temperature difference,

v is the wind speed, and

B, C are functions describing the house and surroundings.

WHEN NORMALIZING TO STANDARD CONDITIONS, THE RELATIVE CHANGE IN THE SPECIFIC LEAKAGE AREA EQUALS THE RELATIVE CHANGE IN THE VENTILATION RATE.

Figure 6. Correcting ventilation rates to standard conditions

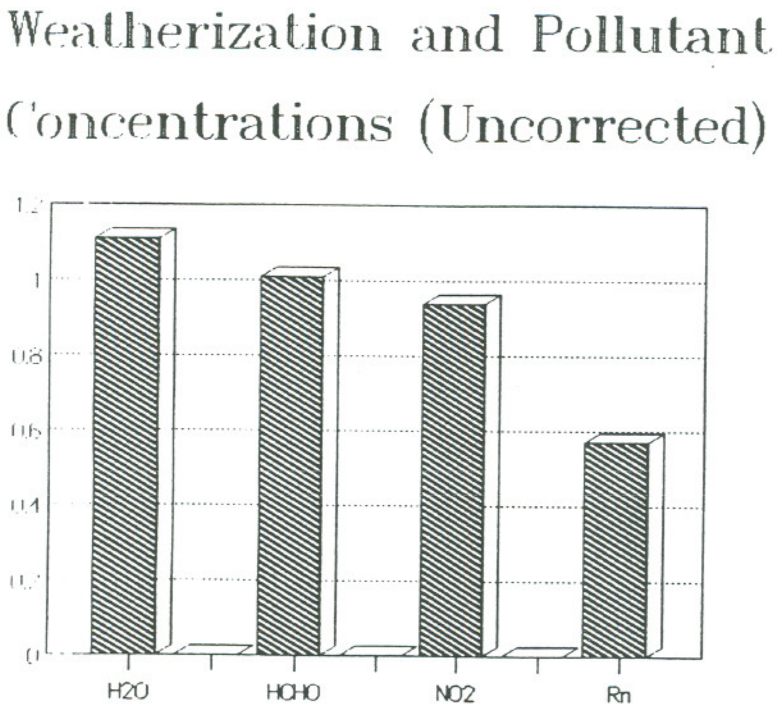


Figure 7. Uncorrected ratios of pollutant concentrations after weatherization to those before weatherization.

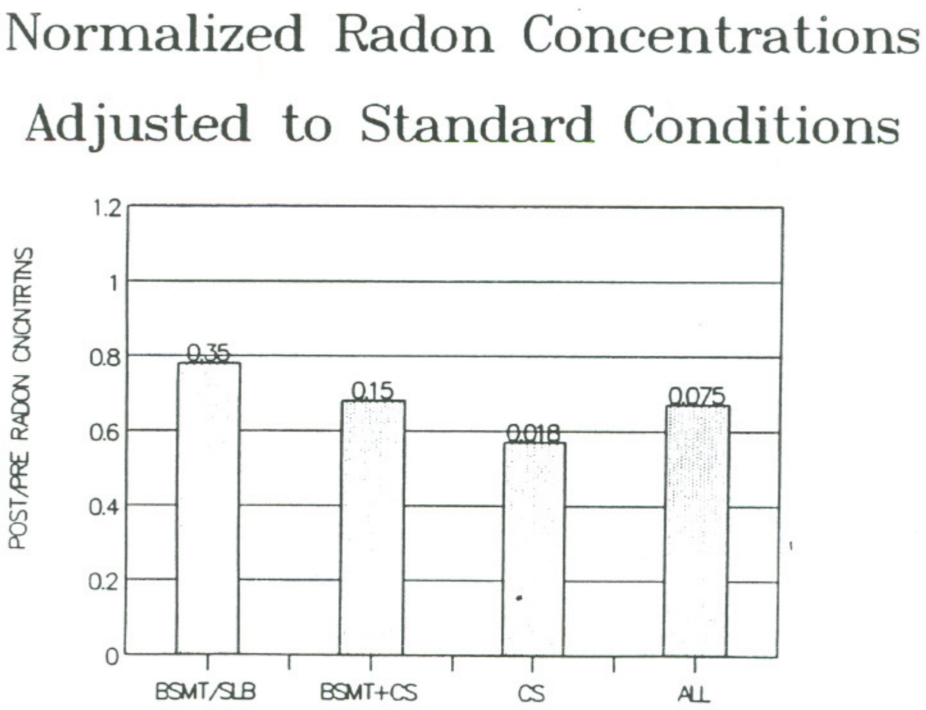
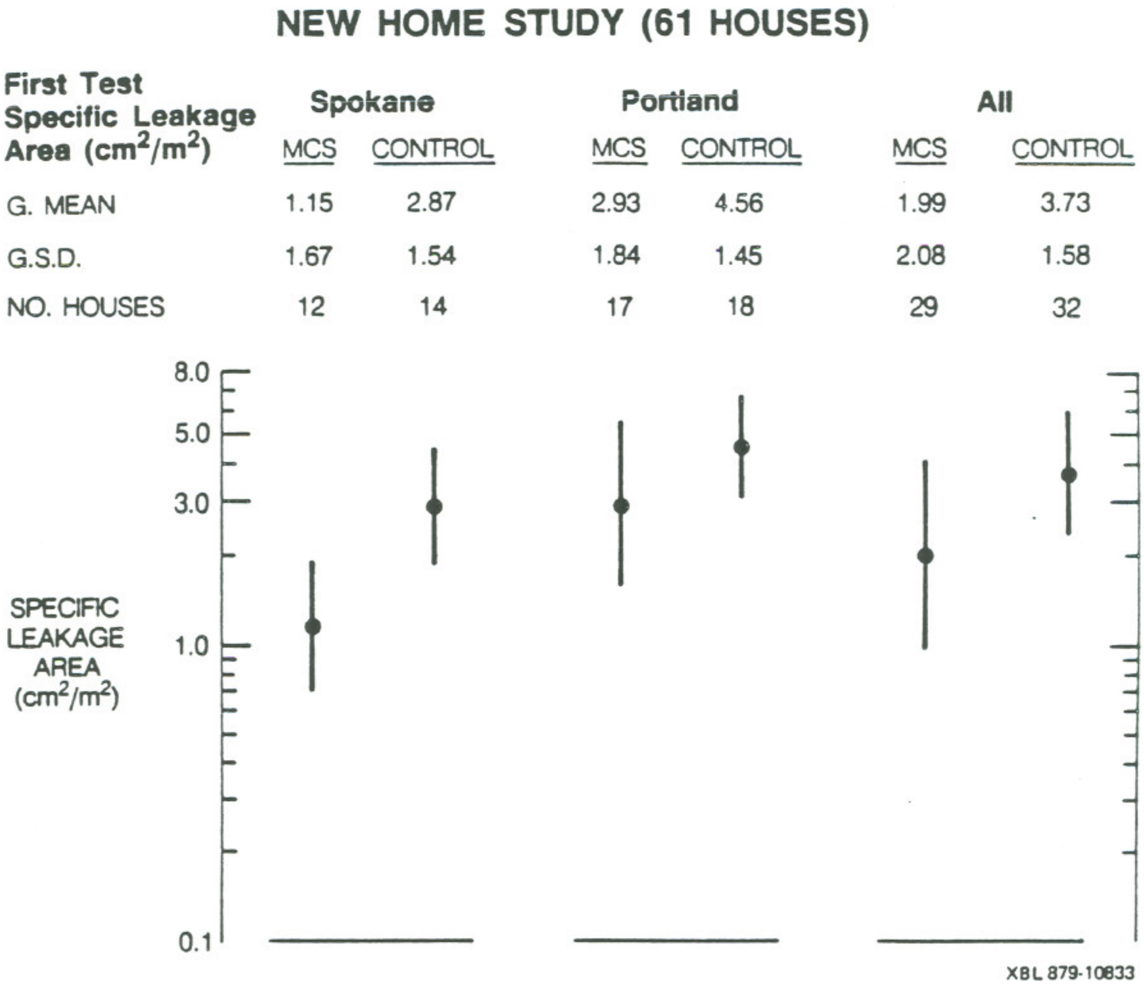


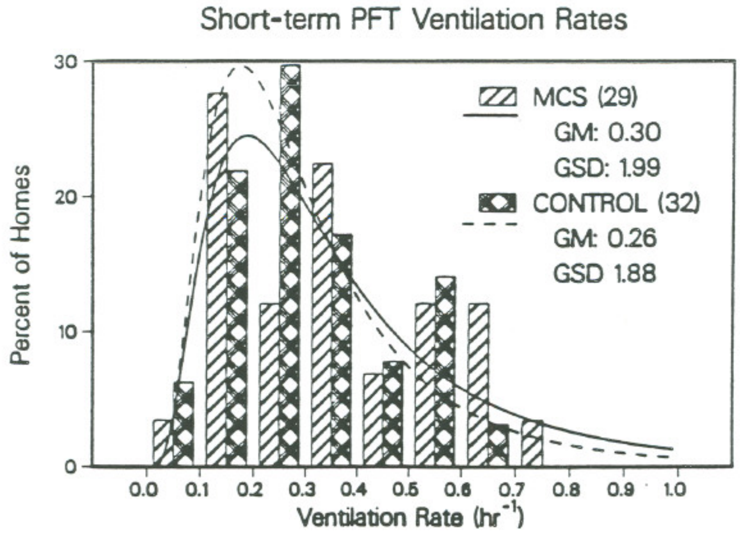
Figure 8. Ratio of post-weatherization to pre-weatherization radon concentrations (corrected) sorted by foundation type. The figures above the bars are the probabilities that the means from the pre- and post-weatherization distributions are the same.



NEW HOME STUDY (61 HOUSES)

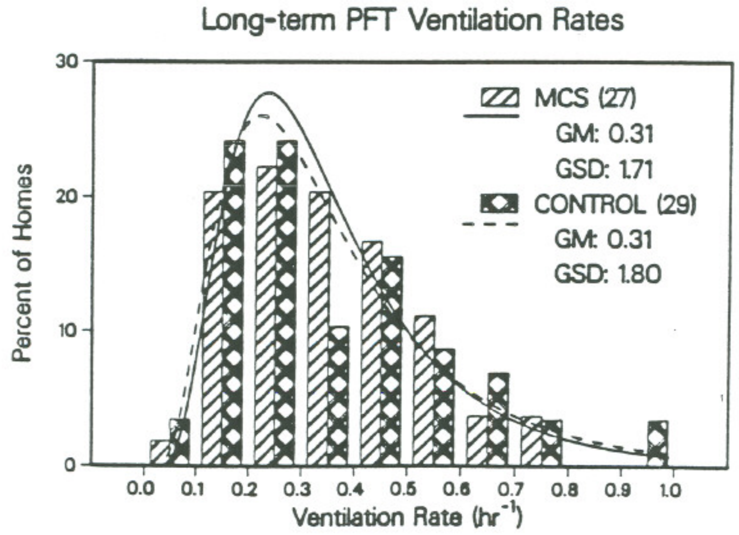
First Test Specific Leakage Area (cm^2/m^2)	Spokane		Portland		All	
	MCS	CONTROL	MCS	CONTROL	MCS	CONTROL
G. MEAN	1.15	2.87	2.93	4.56	1.99	3.73
G.S.D.	1.67	1.54	1.84	1.45	2.08	1.58
NO. HOUSES	12	14	17	18	29	32

Figure 9. Specific Leakage Area test results. The figure shows the geometric mean SLA (dots) and geometric standard deviation of each of the samples listed.



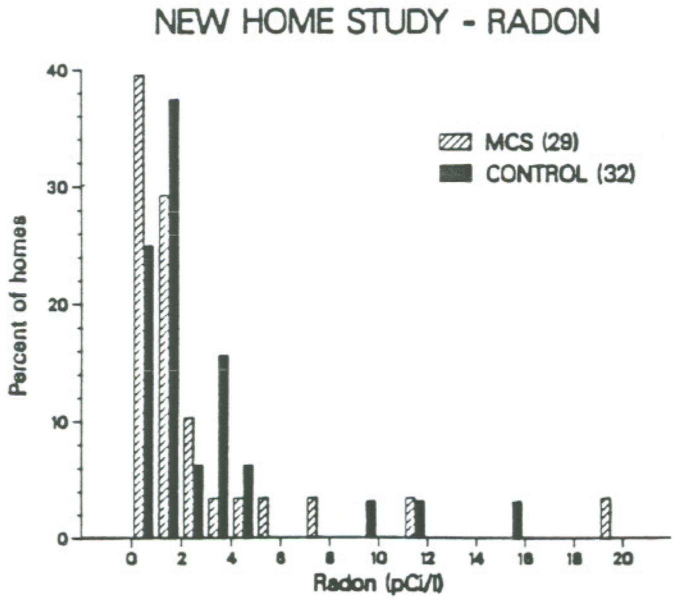
Short-term PFT Ventilation Rates

Figure 7. Short-term ventilation measurements in the MCS and Control houses. The solid and dashed lines are log-normal distributions calculated for the geometric means and geometric standard deviations of the two distributions.



Long-term PFT Ventilation Rates

Figure 10. Short- and long-term ventilation measurements for the MCS and Control houses.



NEW HOME STUDY (61 HOUSES)

RADON (pCi/L)	SPOKANE MCS	SPOKANE CONTROL	PORTLAND MCS	PORTLAND CONTROL	ALL MCS	ALL CONTROL
G. MEAN	1.9	3.5	1.3	1.0	1.5	1.7
G.S.D.	3.8	2.2	2.2	2.2	2.8	2.8
NO. HOUSES	12	14	17	18	29	32

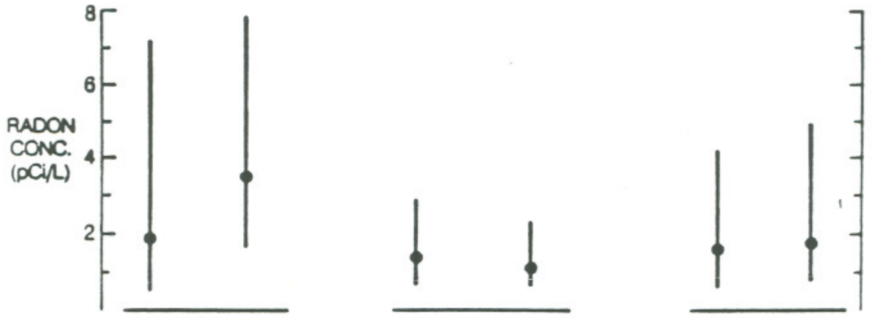


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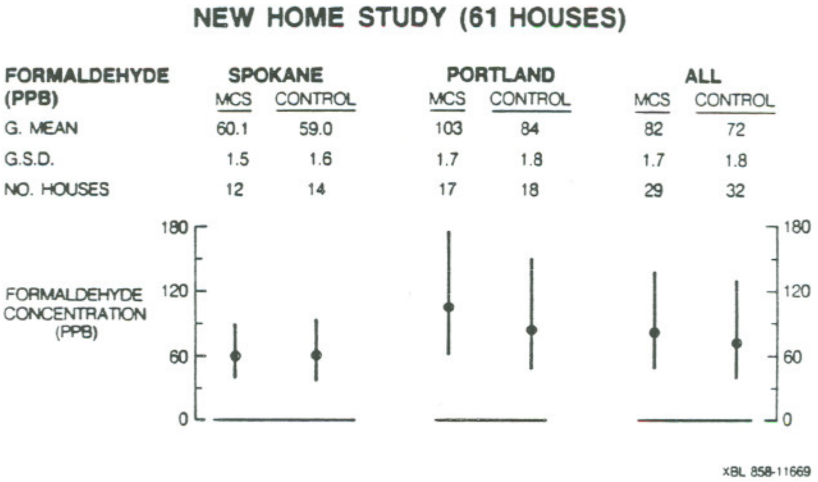
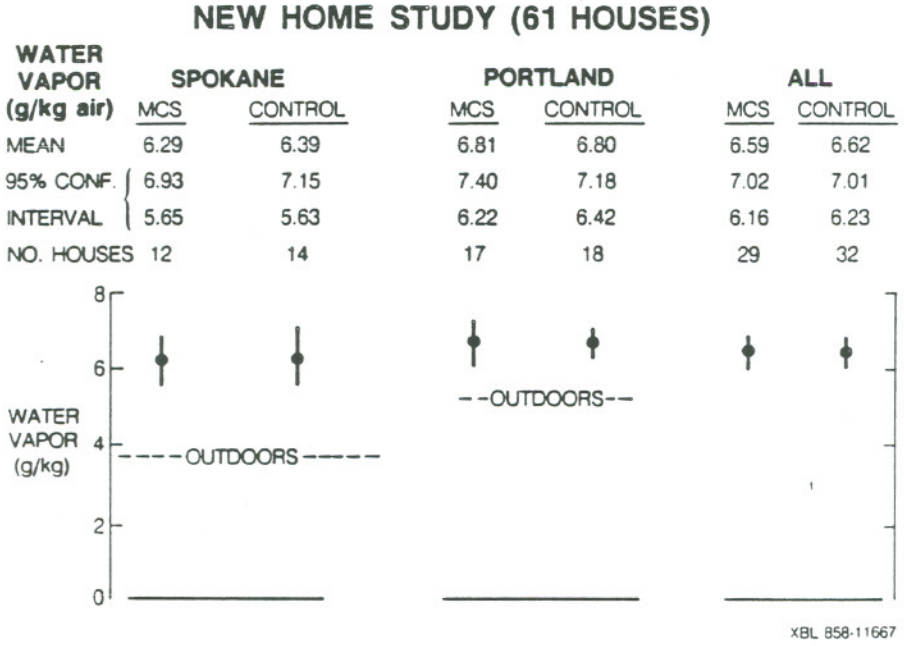
Figure 11. Histogram and regional detail of radon concentrations in MCS and Control houses.



NEW HOME STUDY (61 HOUSES)

FORMALDEHYDE (PPB)	SPOKANE MCS	SPOKANE CONTROL	PORTLAND MCS	PORTLAND CONTROL	ALL MCS	ALL CONTROL
G. MEAN	60.1	59.0	103	84	82	72
G.S.D.	1.5	1.6	1.7	1.8	1.7	1.8
NO. HOUSES	12	14	17	18	29	32

Figure 12. Regional formaldehyde concentrations in MCS and Control houses.



NEW HOME STUDY (61 HOUSES)

WATER VAPOR (g/kg air)	SPOKANE MCS	SPOKANE CONTROL	PORTLAND MCS	PORTLAND CONTROL	ALL MCS	ALL CONTROL
MEAN	6.29	6.39	6.81	6.80	6.59	6.62
95% CONF.	6.93	7.15	7.40	7.18	7.02	7.01
INTERVAL	5.65	5.63	6.22	6.42	6.16	6.23
NO. HOUSES	12	14	17	18	29	32

Figure 13. Regional water vapor concentrations in MCS and Control houses.

APPENDIX A Sampling Instrumentation

Instrumentation used in the three measurement parts of the two studies varied in amount and complexity. Common to all measurement packages were the passive samplers shown deployed in Figure 4. These devices sample air by establishing a pollutant-selective concentration gradient within a tube of known dimension capped at one end (Palmes *et al.*, 1976; Geisling *et al.*, 1982; Girman *et al.*, 1986). The pollutant is collected on an adsorbent or chemically treated disk at the capped end. The samplers were designed to sample continuously for a seven-day period and, upon analysis, provide a measure of the average pollutant concentration. Depending on the house size, indoor nitrogen dioxide (NO_2) and water vapor (H_2O) samples were collected at two to five locations in occupied spaces of each house; one outdoor NO_2 and H_2O sample was taken at each house for reference. Because of their comparatively poor precision, replicate formaldehyde (HCHO) samplers were exposed at each of the indoor and outdoor locations where H_2O and NO_2 were monitored.

Sampling locations were chosen to be separated from important sources of the pollutants being monitored (HCHO: particleboard and other pressed-wood products; H_2O: bathrooms and laundry rooms; NO_2: combustion sources). In addition, sources of temperature extremes, sunlight, and rapid air movement (furnace registers) were avoided as well as areas of air stagnation. Typical sample locations were 2 m high on interior walls of a room representative of the zone being sampled.

Radon (^{222}Rn) was monitored using a Terradex Type SF passive sampler for a period lasting from 55 to 70 days in each house. Two to five samplers were deployed in the occupied space of each house and typically at the sample location of other passive samplers. One to three additional samplers were deployed in unoccupied regions of each house (crawlspaces, basements, and unheated attached utility rooms and storage areas).

Table A-1. 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	