Volume I Environmental Analyses

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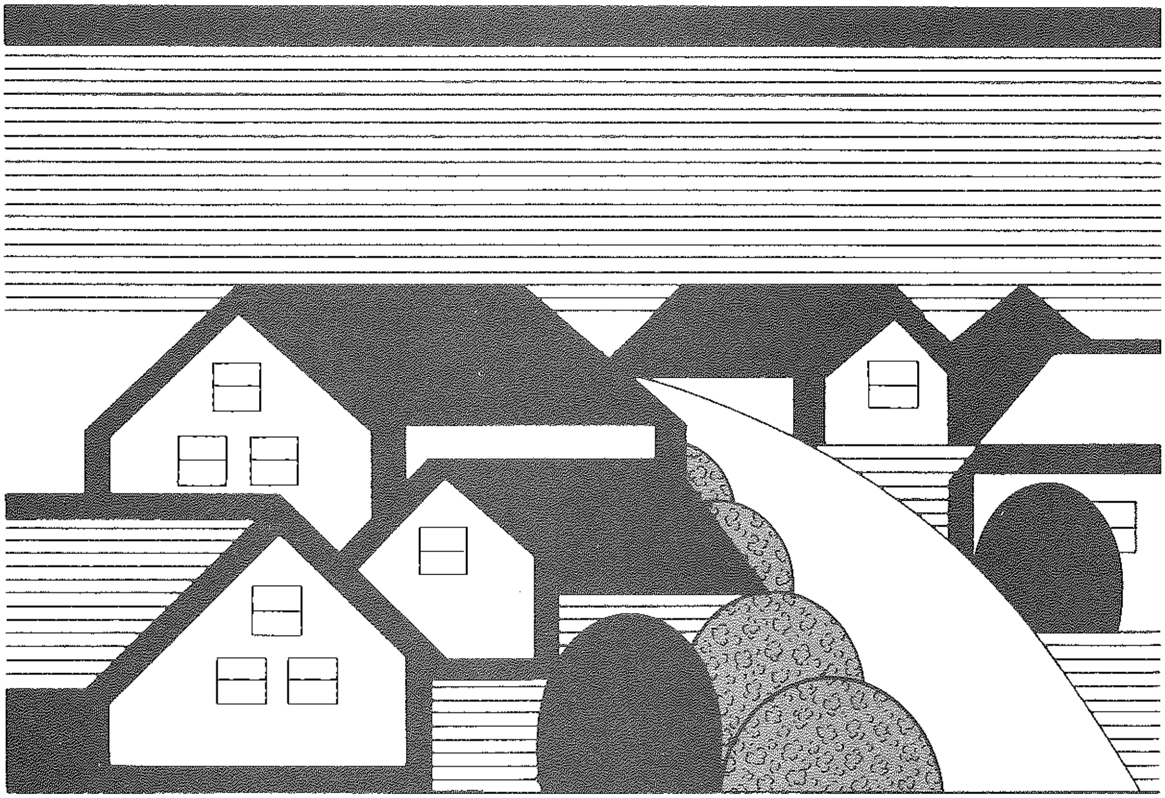
Final Environmental Impact Statement on New Energy-Efficient Homes Programs

U.S. Department of Energy
Bonneville Power Administration

August 1988

DOE/EIS-0127F

Assessing Indoor Air Quality Options



Volume I

BPA

Final Environmental Impact Statement on New Energy-Efficient Homes Programs

Assessing Indoor Air Quality Options

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Responsible Agency: U.S. Department of Energy, Bonneville Power Administration
Title of Proposed Action: New Energy-Efficient Homes Programs
Title of Document: Final Environmental Impact Statement
States Involved: Oregon, Washington, Idaho, and western Montana

Abstract: BPA has implemented marketing and incentive programs and is implementing a surcharge policy to encourage the construction of new energy-efficient homes that comply with Model Conservation Standards (MCS) developed by the Northwest Power Planning Council. These homes are designed to have lower air leakage rates than houses built to today's prevailing building practices, which may increase concentrations of indoor air pollutants and thereby adversely affect the health of occupants. However, MCS also includes measures that can improve indoor air quality (IAQ). BPA's current and past new homes programs maintained ventilation rates comparable to those found in homes built in 1983 by requiring central mechanical ventilation. BPA now proposes to give builders and consumers more flexibility by increasing the options for protecting IAQ in its new homes programs. This proposal is the subject of this Environmental Impact Statement (EIS), which was prepared for BPA by the Pacific Northwest Laboratory. BPA is using this EIS to assess whether other techniques can maintain IAQ comparable to that found in homes built to 1983 practice.

Although many pollutants are potentially of concern and are assessed qualitatively in the EIS, our analysis focuses on the relationship between ventilation rates and concentrations of radon and formaldehyde. The analysis is based on measurements of ventilation and concentrations of these pollutants taken in homes built to 1983 practice. Ventilation was measured using fan pressurization tests, which measure only air leakage, and perfluorocarbon tracer gas tests, which account for ventilation from mechanical devices and occupant behavior in addition to air leakage. These tests yielded a very wide range of estimated ventilation rates. Guided by these estimates, BPA created a range and used upper and lower estimates from within that range to estimate pollutant concentrations and expected lifetime lung cancer rates under the Baseline and four alternative actions. Under all of these, radon had a much greater effect than formaldehyde.

1. Baseline: The Baseline is the starting point of the analysis; it represents the building practices that would prevail in the Northwest absent BPA's new homes programs. We used the following upper and lower estimated values of ventilation to describe baseline conditions: 0.49 air changes per hour (ACH) and 0.36 ACH. All four of the alternatives are assessed relative to both of these Baseline estimates.

2. No Additional Action Alternative: This alternative consists of BPA's 1986-7 new homes programs, primarily marketing, code adoption activities, and financial incentives. The programs are designed to achieve at least the same IAQ as achieved in homes built to 1983 practice. As a result of IAQ requirements in these programs, we assume the same ventilation rates as in the Baseline. For the same reason, expected lifetime cancer rates are also the same as those under the Baseline. Because of the energy-efficient homes in this alternative, there are estimated regional energy savings of 97-104 average megawatts from single-family homes, 21-28 average megawatts from multifamily homes, and about 38 average megawatts from manufactured homes over the Baseline.

3. Proposed Action Alternative: This alternative consists of the same programs as the No Additional Action, but includes a broad menu of options, making up 11 pathways, to provide flexibility for protecting IAQ (targeted specifically at controlling radon). These 11 pathways result in different ventilation rates, depending on the level of infiltration control, the type of mechanical ventilation system, and the length of time the mechanical ventilation system is operated. Lifetime cancer rates of the 11 pathways have a wide range, varying from slightly less than the Baseline to far above the Baseline. For single-family homes, energy savings range from 74 to 148 average megawatts; for multifamily homes, 11 to 39 average megawatts; and for manufactured homes, 28 to 41 average megawatts over the Baseline.

4. Preferred and Environmentally Preferred Alternative: From the 11 pathways in the Proposed Action, BPA has chosen Pathways 3, 5, 6, 8, and 10 for its Preferred Alternative. This alternative results in a slightly lower cancer rate than the Baseline for all three housing types. It results in 158 to 165 average megawatts of energy savings over the Baseline. Pathway 8 is the Environmentally Preferred Alternative; this pathway improves public health and shows the greatest health benefits relative to the Baseline. It also results in more energy savings than both the Baseline and the Preferred Alternative, but at a higher cost to BPA and less flexibility for builders.

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SUMMARY

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Bonneville Power Administration (Bonneville) promotes the construction of new energy-efficient homes through a variety of programs. These programs include such features as marketing and incentive payments to encourage the construction of energy-efficient homes, financial assistance to jurisdictions that incorporate Model Conservation Standards (MCS) into building codes, and implementation of a surcharge policy. The MCS are energy-efficient performance standards, which were development by the Northwest Power Planning Council (Council), for electrically heated buildings. The purpose of these programs is to save energy in new homes in compliance with provisions of the Pacific Northwest Electric Power Planning and Conservation Act, (Public Law 96-501). This law mandates Bonneville to:

- acquire all necessary energy resources to serve Northwest utilities choosing to acquire power from the agency (Bonneville serves customers in the states of Idaho, Montana, Oregon, and Washington);
- give cost-effective conservation highest priority in responding to the demand for electricity;
- promote the Council's MCS for the construction of energy-efficient homes as a means of controlling future electrical load growth though conservation;
- levy a rate surcharge on utilities that serve territories where reasonable steps are not being taken to save energy from MCS or other programs acceptable of Bonneville and the Council.

The primary environmental issue for new energy-efficient homes is whether tighter construction increases indoor air pollution, which may in turn adversely affect the health of the occupants. To date, Bonneville has prevented or reduced this possible effect in energy-efficient homes built under its programs by either (1) using mechanical ventilation (MV) systems to maintain ventilation rates at levels generally found in homes built when the MCS were first adopted (1983 building practice), or (2) requiring monitoring and mitigation of formaldehyde and radon levels above 0.1 parts per million (ppm) or 5 picoCuries per liters (pCi/l), respectively.

Bonneville has prepared this Environmental Impact Statement (EIS) to explore whether other approaches will control indoor air quality (IAQ) and still maintain cost-effective energy savings. Its purpose is to provide builders and consumers with more flexibility in how they control IAQ in energy-efficient homes. Different building techniques and mitigation measures are analyzed for their ability to maintain IAQ comparable to that found in 1983 building practices, or to even improve it.

THE PATHWAYS

To give builders and consumers the flexibility mentioned above, a broad menu of practical, commercially available methods are combined to make up 11 pathways.

All of the pathways start with consumer information packets; the offer of radon monitoring; radon preparatory construction measures (e.g., sub slab gravel, crawlspace ventilation) or required monitor and mitigation; exhaust fans in kitchens, bath, and utility rooms; and formaldehyde product standards for particle board and plywood. The proposed program includes two types of energy-efficient homes: homes with advanced air leakage control packages (i.e. air barriers) built with very low infiltration rates, and those with more standard air leakage control measures (i.e., well-sealed with caulking and weather stripping), which result in higher infiltration rates still below those of current practice.

The pathways are structured around three key variables:

1) the infiltration control applied to the house;

2) the mechanical ventilation (MV) system which includes four choices:

- no whole-house MV system,
- central mechanical ventilation with heat recovery (e.g., an air-to-air heat exchanger (AAHX)),
- central mechanical exhaust ventilation system with openings for outside air supply, and,

3) the occupants' operation of the MV system.

The three basic MV systems are sized to provide different capacities.

We analyzed two operating or control options. A continuously operating (24-hr) MV system results in a controlled, constant rate of air exchange. The other option is intermittent operation and assumes the system operates 8 hrs per day. The second option acts as a proxy in the analysis for control technologies that are not widely available and used today but that are likely to be commonplace in new homes by the year 2000. These controls would be triggered by such things as occupancy, humidity, and pollution levels. The pathways are described below.

Pathway 1. Pathway 1 applies to well-sealed energy-efficient houses that do not have air barriers as one of the conservation measures. This pathway has no central MV system, relying only on dehumidifiers and exhaust fans for spot ventilation. Since incidental mechanical ventilation is not included in the calculation of the total ventilation rates, the rates are the same as the design ventilation rates of well-sealed houses without air barriers: (0.35 and 0.28 effective air changes per hour (ACH) for upper and lower bound estimates, respectively).

Pathway 2. Pathway 2 also applies to houses with standard infiltration control, but whole-house, balanced, mechanical ventilation, operating continuously, is sized to give ventilation levels equivalent to, or greater than, current practice (0.53 and 0.47 effective ACH for upper and lower bound estimates, respectively). Wall- or window-mounted balanced MV devices may be used, but several may be needed to achieve a "whole-house" effect.

Pathway 3. Pathway 3 is the counterpart of Pathway 2. Everything is the same, except that the MV system operates intermittently, for a total of 8 hrs per day instead of 24. This intermittent operation results in a lower effective ventilation rate than Pathway 2 (0.41 and 0.35 effective ACH for upper and lower bound estimates, respectively).

Pathway 4. In Pathway 4, the standard infiltration control is combined with a central exhaust MV system, instead of an AAHX, which intakes to supply makeup air. The system is operated continuously and provides an effective ventilation rate of 0.48 and 0.40 effective ACH for upper and lower bound estimates, respectively.

Pathway 5. Pathway 5 is identical to Pathway 4, except for intermittent operation of the MV system. The intake ports provide the makeup air to give a pressure-balanced system; the also provide better distribution of the makeup air because of their placement. Because of MV system is operated only 8 hrs per day, this pathway results in lower ventilation rates (0.42 and 0.34 effective ACH for upper and lower bound estimates, respectively).

Pathway 6. Pathway 6 is a variant of Pathway 5; its difference is the absence of intake vents for makeup air supply, which results in an unbalanced system and ventilation rates of 0.38 and 0.31 effective ACH for upper and lower bound estimates, respectively.

Pathway 7. Pathway 7 represents one of the extreme options but is included for completeness of analysis. It applies to houses that take the advanced approach to infiltration control by installing a continuous air barrier, but the home includes no MV system. Therefore, no ventilation is added to the natural infiltration rate, resulting in the lowest effective ventilation: 0.18 and 0.156 effective ACH for upper and lower bound estimates, respectively.

Pathway 8. Pathway 8 includes continuously operating, whole-house, balanced, mechanical ventilation in energy-efficient houses built with air barriers. Even with the air barrier, the continuously operating AAHX provides an effective ventilation rate equivalent to current practice: 0.43 and 0.40 effective ACH for upper and lower bound estimates, respectively.

Pathway 9. Pathway 9 is identical to Pathway 8 except the AAHX operates intermittently and this results in significantly lower ventilation rates: 0.27 and 0.23 effective ACH for upper and lower bound estimates, respectively.

Pathway 10. Pathway 10 consists of advanced air leakage control and a whole-house exhaust MV system operating continuously. Although the technology for an automatic continuously operating exhaust system is available and is in use in Europe, it has not yet been widely introduced in the U.S., but will be in the future. This pathway has effective ventilation rates of 0.34 and 0.31 for upper and lower bound estimates, respectively.

Pathway 11. Pathway 11 is identical to Pathway 10 except the exhaust MV system operates only 8 hours per day, resulting in lower ventilation rates: 0.26 and 0.22 effective ACH for the upper and lower bound estimates, respectively.

These 11 pathways encompass the extremes of options available for construction of new energy-efficient homes in the Pacific Northwest. While some pathways appear unreasonably extreme, they all fall within the bounds of reality and completely frame the range of reasonable choices.

BASELINE AND ALTERNATIVES

We chose four alternatives to assess and compare environmental effects. The alternatives were determined by the fundamental issue to be explored through the EIS: maintaining the current action, which relies on a limited approach for protecting IAQ (maintaining ventilation levels that prevailed in 1983 buildings through a combination of infiltration and mechanical ventilation) or broadening that approach by adding other means of protecting IAQ. The decision to be made is whether all or some IAQ pathways in the Proposed Action Alternative should be adopted. An important element of our analysis of the alternatives is BPA's forecast of new home construction. The forecast estimates both the number of new homes which will be built to prevailing building practice and the number built to energy-efficient standards for the planning period 1986 through 2006. These estimates are given in the following description of the Baseline and four alternatives.

Baseline: The Baseline is derived from BPA's 1986 medium housing forecast for the Pacific Northwest and the assumption that no energy-efficient new homes programs are underway. In the Baseline we estimate that, from 1986 through 2006, about 2.9 million people will live in some 603,300 new electrically heated single-family homes, some 356,800 multifamily homes, and 247,300 manufactured homes, all built to prevailing construction practices (hereafter referred to as "current practice homes").

No Additional Action Alternative: The No Additional Action Alternative represents the programs BPA has pursued since 1985 to promote new energy-efficient home construction. In these programs, BPA has supplied technical and sales training, cooperative advertising funds, a regional marketing campaign, financial incentives, and information about IAQ. There were also programs aimed at technology transfer and code adoption. Analysis of this alternative assumes the marketing program continues from 1986 through 2006.

By the year 2006 about 1.3 million people are forecast to be residing in 436,600 new single-family, electrically heated homes, of which 270,800 will be built to MCS standards; some 568,800 living in 354,900 multifamily homes, of which 228,100 are energy-efficient; and 570,400 living in 247,300 manufactured homes, of which 59,700 are energy-efficient.

Proposed Action Alternative: The Proposed Action Alternative is identical to the No Additional Action Alternative in regard to programs, number of participants, and number of current practice and energy-efficient homes built. However, unlike the other alternatives, this one has a broad menu of building techniques and mitigation measures from which builders and consumers may choose to maintain IAQ. These measures are combined into a set of 11 "pathways".

All pathways in the Proposed Action require the radon package, which includes the offer of radon monitoring to all households. It also includes the option of installing measures (a ventilated crawlspace and/or a gravel base under a concrete slab floor) which would allow more effective mitigation of radon if the homeowner chooses. Those homes for which builders have not installed these measures for post-construction source control require monitoring for radon concentrations. If monitoring shows that levels exceed 5 pCi/l, mitigation techniques must be installed and activated. We assume these actions reduce concentrations by 70 percent(%).

Preferred Alternative: Bonneville considered a number of factors in the selection of the Preferred Alternative; of these "decision factors", health effects and flexibility were particularly important. For the first criterion we chose pathways for which health effects were close enough to those in the Baseline to be within the range of uncertainty. For the second criterion, within the tolerances allowed by the uncertainty surrounding the health effects and energy savings, we wished to allow maximum flexibility for builders and utilities. Based on these criteria, BPA has chosen to include Pathways 3, 5, 6, 8, and 10 in its Preferred Alternative.

Environmentally Preferred Alternative: This alternative would result in the greatest overall health benefits to the population through reduced incidence of lung cancer and reduced impacts from alternative generating resources relative to the Baseline. Pathway 8 of the Proposed Action represents this alternative.

VENTILATION

Our analysis of health effects is based on estimated changes in ventilation rates in new energy-efficient homes compared to those in houses built to 1983 building practice. We realize the most important factor in determining the health risk for each individual is the actual pollutant concentration in the home, which is based on the interaction between strength of the pollutant source and the infiltration of fresh air. Because pollutant source strengths and indoor concentrations vary widely, we decided to use average pollutant concentrations with varying ventilation rates to estimate health effects. If one assumes that homes built under BPA's program would have been built without the program in approximately the same geographic locations and in the same basic configurations, then changes in ventilation rates becomes a valid predictor of health effects. As the purpose of this EIS is to compare impacts of various alternatives to those estimated for the Baseline, this assumption is acceptable.

Since 1984 BPA has measured ventilation rates in newly constructed homes as part of its Residential Standards Demonstration Program (RSDP). Two measurement techniques were used. The first technique uses a blower door and relies on the principle of fan pressurization to measure an equivalent leakage area (ELA), which can be thought of as the sum of all the holes and cracks of the building's envelope or exterior shell. The ELA was combined with typical weather conditions and additional assumptions regarding the home's physical characteristics to estimate an average natural ventilation rate for the heating season. The second technique uses a perfluorocarbon tracer (PFT) gas test, which measures a building's "effective" ventilation rate. The result of the PFT test includes the effects of a home's MV system and of occupant behavior in addition to the naturally occurring infiltration rate. Simply stated, the ventilation rate estimated by the PFT test is a tracer "dilution rate" and is called the "effective ventilation rate."

Baseline: These two ventilation measurement techniques have yielded different results within the same house. The fan pressurization test generally yields higher average results than the PFT test and spans a broader range of results. However, we believe these two tests are representative of the uncertainty in residential ventilation rates and our inability to accurately determine the rate in any particular home. If we could accurately measure a home's ventilation rate, we estimate the actual rate would lie between the results of these two tests. Given this uncertainty and guided by the previous testing experience, BPA elected to develop ventilation rates for the various alternatives in this EIS by establishing upper and lower bound estimates. These estimates not only account for the uncertainty but also provide a range of environmental effects which is linked to the actual distribution of ventilation rates found in homes. The values used for the Baseline and the other alternatives are given in Tables 1 through 3.

Note that for all three housing types (Tables 1-3) identical ventilation rates are given for the Baseline and the No Additional Action Alternative. Since the current New Energy-Efficient Homes Programs, which compose the No Additional Action Alternative, are designed to maintain IAQ at least comparable to 1983 practice, we assume the ventilation rates are the same as the Baseline.

Proposed Action Alternative: Ventilation rates for the Proposed Action Alternative depend on the characteristics of each pathway. For example, the alternative includes two types of energy-efficient homes: homes with advanced air leakage control packages (i.e., air barriers) built with very low infiltration rates (Pathways 7-11); and homes with more standard air leakage control measures (i.e., well-sealed with caulking and weatherstripping), which result in higher infiltration rates but still below those of 1983 practice (Pathways 1-6).

Three ventilation options are possible for both types of houses. That is, the five pathways for homes with air barriers, and thus very low infiltration rates, include the same ventilation options as the six pathways for homes with standard infiltration control (with one exception). Those options are: 1) whole-house mechanical ventilation with heat recovery (AAHX); 2) a central mechanical exhaust ventilation system (with controlled openings for outside air supply); or 3) no MV system, but only spot ventilation with exhaust fans. Houses with the standard infiltration control have one other option, a distributed exhaust system with a larger capacity fan but without controlled openings for outside air. This pathway requires houses to be checked and to achieve a minimum leakage area.

The amount of ventilation provided by these ventilation systems depends in part on their frequency of operation. They can operate either continuously or intermittently (up to 8 hr/day); the continuously operated system provides more ventilation than one operated intermittently.

Preferred Alternative: Ventilation rates for this alternative come from the various pathways selected to compose this alternative. In evaluating this alternative, we assume each pathway is represented by a percentage of all new energy-efficient homes. The percentages change over time to reflect increasing acceptance and use of newly available technology in MV systems.

Environmentally Preferred Alternative: The ventilation rate for this alternative is the same as that estimated for pathway 8 of the Proposed Action Alternative.

INDOOR AIR QUALITY

The primary environmental concern for the New Energy-Efficient Homes Programs is the effects that increased levels of indoor pollutants may have on residents' health. Many factors affect the level and mix of pollutants found in a given home, including source strength, house volume, occupant behavior, and ventilation rates. Reducing air flow between indoors and outdoors is an effective way to conserve energy, but may also contribute to the buildup of indoor pollutants.

To determine the health effects of the Baseline and the various alternatives, our quantitative analysis focuses on radon and formaldehyde. We emphasize these two pollutants for a number of reasons. 1) These two pollutants are commonly found indoors and have effects ranging from short-term discomfort to possible incidence of lung cancer. 2) Occupants have less control over the presence of these pollutants in homes than over other pollutants because their presence is affected only indirectly by occupant decisions and behavior and more by the pollutant source term. Pollutants inherent in the site or structure of a home are more likely to be affected by changes in ventilation than by occupant behavior; this is especially true of radon. Exposure to other pollutants results from individuals' choices such as smoking tobacco, using a wood stove, or pursuing particular hobbies. 3) Radon and formaldehyde levels can be affected through builders' construction decisions. 4) Finally, researchers have developed risk factors for these pollutants, making it possible to quantify lifetime cancer rates based on concentration levels over long time periods. Whereas no short-term or acute health symptoms are associated with radon, scientists have found that formaldehyde can cause severe, short-term health effects; however, these effects are not quantifiable and sensitivity among exposed persons differs.

Other indoor pollutants, such as respirable suspended particulates (RSP), combustion gases, household chemicals, moisture, and microorganisms also pose problems. However, our review of the scientific literature indicates insufficient information to accurately quantify or to be definitive about the health effects of these pollutants.

We based our analysis on concentration data taken from 1983 single-family homes monitored as part of BPA's RSDP. Using measured concentrations of radon and formaldehyde and estimated ventilation rates from these homes, along with prototypical sizes of single-family, multifamily, and manufactured homes, we estimated pollutant concentrations to match different ventilation rates and housing types.

Baseline: Radon measurements were divided into two groups, readings below and above 5 pCi/l, for the region's three climate zones. Then median values were obtained for each group by climate zone. For single-family homes, the group below 5 pCi/l had values of 0.41, 1.51, and 2.23 pCi/l for climate zones 1, 2, and 3, respectively. The median values for the group above 5 pCi/l were 10.52, 9.56, and 9.76 for the same climate zones. The number of homes falling into the respective groups was based on the percentage of measurements within the two groups by climate zone. Formaldehyde concentrations in single-family homes were 0.09 ppm for all three climate zones.

No Additional Action Alternative: Since the current New Energy-Efficient Homes Programs, which compose the No Additional Action Alternative, are designed to maintain IAQ at least comparable to 1983 practice, we assumed the concentrations in the various housing types are the same as the Baseline.

Proposed Action Alternative: Radon and formaldehyde concentrations for the different housing types were estimated for each pathway by increasing or decreasing the Baseline's concentrations by the magnitude of change in the ventilation rate. For example, single-family homes in Pathway 1 have ventilation rates 71 and 74% of the upper and lower estimates of the Baseline's ventilation rates. Since concentration is inversely proportional to ventilation rate, the concentrations for Pathway 1 will be 1.41 and 1.35 times those for the upper and lower values in 1983 houses. Using this approach, concentrations were estimated for each pathway for each housing type. If the measured concentrations exceeded 5 pCi/l and mitigation measures were implemented, we assumed concentrations were reduced by 70% to account for implementation of the radon package. However, we assume only a small fraction of the homes with estimated concentrations above 5 pCi/l will implement the radon mitigation measures, that is, only those homes with large measured radon concentrations.

Preferred Alternative: Since this alternative is made up of various pathways from the Proposed Action Alternative, concentrations are the same as those estimated for the selected pathways of that alternative.

Environmentally Preferred Alternative: Since Pathway 8 represents this alternative, the concentrations are the same as estimated for that pathway.

HEALTH EFFECTS

The key health effect in this EIS is lifetime lung cancer from exposure to radon and nasal cancer from formaldehyde. We estimated the number of lifetime cancers that may occur per 100,00 persons exposed to estimated concentrations of radon and formaldehyde that may be found in energy-efficient homes. We based our estimates of lifetime cancers on the assumption of a "linear dose response": that the likelihood of contracting cancer is directly proportional to pollutant exposure (doubling the exposure doubles the risk). We assumed that cancers occur at all pollutant levels and that there is no threshold below which pollutant levels do not result in a risk of cancer. We also assumed that we can use information about risks from exposure to pollutants at high concentrations to calculate risks at low concentrations; this assumption is known as high-to-low dose extrapolation.

Lifetime cancer rates for each of the alternatives are listed in Tables 1 through 3 for single-family, multifamily, and manufactured homes. The numbers in these tables are an approximation of relative changes in risk and do not predict what will actually occur. We have estimated not the certain incidence of cancer for a given individual, but rather the probability of lung cancer for each individual of a larger population at risk.

Baseline: We estimated 335 lifetime cancers per 100,000 persons result from radon exposure and 10 lifetime cancers per 100,000 result from formaldehyde in single-family homes. In manufactured homes, a rate of 413 lifetime cancers per 100,000 persons is estimated for exposure to radon and 12 for formaldehyde. In multifamily homes the cancer rate from radon is 306 per 100,000 and 12 for formaldehyde.

No Additional Action Alternative: There is no increase in cancer rates from this Alternative because ventilation rates are identical to the Baselines's ventilation rates.

Proposed Action Alternative: We estimated the health effects for each pathway of the Proposed Action by using both the upper and lower estimates of ventilation and by assuming that all new energy-efficient homes would follow that pathway. The estimated lifetime cancer rates given in Tables 1 through 3 all show the same pattern: as ventilation rates decrease, cancer rates increase. For single-family homes, the lowest lifetime cancer rate from radon is 277-293 for Pathway 2, which has the highest ventilation rate. The highest lifetime cancer rate is 601-629 for Pathway 7, which has the lowest ventilation rate. Another pattern is more clearly illustrated in Figure 1: with the exception of Pathways 1, 7, 9, and 11, the health effects of the various pathways are not very different from one another, nor from the Baseline.

To help put the risk estimates of lifetime lung cancers in context, the following risk comparisons can be made. For each comparison we assume exposure occurs over a lifetime. Exposure to 1 pCi/l of radon is equivalent to the risk of contracting lung cancer from smoking 1/4 or less of a cigarette per day. Exposure to 5 pCi/l is equivalent to the risk from smoking about 1 cigarette per day.

Finally, the relative differences between the estimates are much more important than the absolute numbers for comparing the health effects of the alternatives to the Baseline. These numbers may not represent absolute or "true" effects, but they do convey the relative consequences of the various alternatives so BPA is able to select among alternative actions to make a policy decision.

TABLE 1. Environmental Impacts of the Alternative Actions Associated with Single-family Dwellings

Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Baseline								
Upper	0	603,337	1,799,281	--	0.45	335	10	0
Lower	0	603,337	1,799,281	--	0.35	335	10	0
No Additional Action								
Upper	270,808	436,630	1,305,409	0.45	0.45	335	10	104
Lower	270,808	436,630	1,305,409	0.35	0.35	335	10	97
Proposed Action:								
Pathway 1								
Upper	270,808	436,630	1,305,409	0.32	0.45	396	12	113
Lower	270,808	436,630	1,305,409	0.26	0.35	385	12	107
Pathway 2								
Upper	270,808	436,630	1,305,409	0.52	0.45	293	9	107
Lower	270,808	436,630	1,305,409	0.45	0.35	277	8	87
Pathway 3								
Upper	270,808	436,630	1,305,409	0.37	0.45	360	11	115
Lower	270,808	436,630	1,305,409	0.31	0.35	343	11	95
Pathway 4								
Upper	270,808	436,630	1,305,409	0.45	0.45	319	10	78
Lower	270,808	436,630	1,305,409	0.38	0.35	304	9	74
Pathway 5								
Upper	270,808	436,630	1,305,409	0.38	0.45	354	11	97
Lower	270,808	436,630	1,305,409	0.31	0.35	343	11	93
Pathway 6								
Upper	270,808	436,630	1,305,409	0.35	0.45	373	12	105
Lower	270,808	436,630	1,305,409	0.29	0.35	358	11	99

TABLE 1. (Continued)

Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons[c]	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Pathway 7								
Upper	270,808	436,630	1,305,409	0.17	0.45	629	20	148
Lower	270,808	436,630	1,305,409	0.14	0.35	601	19	134
Pathway 8								
Upper	270,808	436,630	1,305,409	0.43	0.45	328	10	134
Lower	270,808	436,630	1,305,409	0.40	0.35	295	9	114
Pathway 9								
Upper	270,808	436,630	1,305,409	0.21	0.45	537	17	140
Lower	270,808	436,630	1,305,409	0.18	0.35	499	16	120
Pathway 10								
Upper	270,808	436,630	1,305,409	0.34	0.45	381	12	113
Lower	270,808	436,630	1,305,409	0.30	0.35	351	11	99
Pathway 11								
Upper	270,808	436,630	1,305,409	0.24	0.45	486	15	131
Lower	270,808	436,630	1,305,409	0.20	0.35	462	14	119
Preferred Alternative								
Upper	270,808	436,630	1,305,409	N/A	N/A	352	11	111
Lower	270,808	436,630	1,305,409	N/A	N/A	352	10	100
Environmentally Preferred Alternative								
Upper	270,808	436,630	1,305,409	0.43	0.45	328	10	134
Lower	270,808	436,630	1,305,409	0.40	0.35	295	9	114

(a) Total number of single-family homes projected through 2006.

(b) Lifetime cancer rates include both energy-efficient and baseline homes. The net effect of BPA's activities can be estimated by subtracting the lifetime cancer rate of the Baseline from those of the alternatives.

(c) HCHO=formaldehyde

TABLE 2. Environmental Impacts of the Alternative Actions Associated with Multifamily Dwellings

Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Baseline								
Upper	0	356,889	573,395	--	0.30	306	12	0
Lower	0	356,889	573,395	--	0.20	306	12	0
No Additional Action								
Upper	228,159	353,991	568,819	0.30	0.30	306	12	28
Lower	228,159	353,991	568,819	0.20	0.20	306	12	21
Proposed Action:								
Pathway 1								
Upper	228,159	353,991	568,819	0.19	0.30	419	16	36
Lower	228,159	353,991	568,819	0.15	0.20	371	15	27
Pathway 2								
Upper	228,159	353,991	568,819	0.45	0.30	240	9	32
Lower	228,159	353,991	568,819	0.40	0.20	208	8	21
Pathway 3								
Upper	228,159	353,991	568,819	0.24	0.30	355	14	35
Lower	228,159	353,991	568,819	0.20	0.20	306	12	24
Pathway 4								
Upper	228,159	353,991	568,819	0.47	0.30	235	9	16
Lower	228,159	353,991	568,819	0.42	0.20	203	8	11
Pathway 5								
Upper	228,159	353,991	568,819	0.29	0.30	312	12	28
Lower	228,159	353,991	568,819	0.24	0.20	273	11	21
Pathway 6								
Upper	228,159	353,991	568,819	0.24	0.30	355	14	29
Lower	228,159	353,991	568,819	0.19	0.20	316	12	24

TABLE 2. (Continued)

Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Pathway 7								
Upper	228,159	353,991	568,819	0.12	0.30	599	24	39
Lower	228,159	353,991	568,819	0.11	0.20	466	18	29
Pathway 8								
Upper	228,159	353,991	568,819	0.37	0.30	268	11	36
Lower	228,159	353,991	568,819	0.36	0.20	218	9	25
Pathway 9								
Upper	228,159	353,991	568,819	0.15	0.30	502	20	39
Lower	228,159	353,991	568,819	0.14	0.20	390	15	28
Pathway 10								
Upper	228,159	353,991	568,819	0.41	0.30	253	10	22
Lower	228,159	353,991	568,819	0.40	0.20	208	8	13
Pathway 11								
Upper	228,159	353,991	568,819	0.21	0.30	390	15	33
Lower	228,159	353,991	568,819	0.19	0.20	316	12	23
Preferred Alternative								
Upper	228,159	353,991	568,819	N/A	N/A	304	12	30
Lower	228,159	353,991	568,819	N/A	N/A	260	10	24
Environmentally Preferred Alternative								
Upper	228,159	353,991	568,819	0.37	0.30	268	11	36
Lower	228,159	353,991	568,819	0.36	0.20	218	9	25

(a) Total number of multifamily homes projected through 2006.

(b) Lifetime cancer rates include both energy-efficient and baseline homes. The net effect of BPA's activities can be estimated by subtracting the lifetime cancer rate of the Baseline from those of the alternatives.

TABLE 3. Environmental Impacts of the Alternative Actions Associated with Manufactured Homes

Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Baseline								
Upper	0	247,293	570,410	--	0.41	413	12	0
Lower	0	247,293	570,410	--	0.41	413	12	0
No Additional Action								
Upper	59,687	247,293	570,410	0.41	0.41	413	12	39
Lower	59,687	247,293	570,410	0.41	0.41	413	12	37
Proposed Action:								
Pathway 1								
Upper	59,687	247,293	570,410	0.31	0.41	432	13	37
Lower	59,687	247,293	570,410	0.29	0.41	440	13	36
Pathway 2								
Upper	59,687	247,293	570,410	0.53	0.41	384	11	35
Lower	59,687	247,293	570,410	0.50	0.41	388	11	34
Pathway 3								
Upper	59,687	247,293	570,410	0.36	0.41	416	12	35
Lower	59,687	247,293	570,410	0.34	0.41	422	12	33
Pathway 4								
Upper	59,687	247,293	570,410	0.46	0.41	394	11	37
Lower	59,687	247,293	570,410	0.43	0.41	399	12	35
Pathway 5								
Upper	59,687	247,293	570,410	0.38	0.41	411	12	29
Lower	59,687	247,293	570,410	0.35	0.41	419	12	28
Pathway 6								
Upper	59,687	247,293	570,410	0.35	0.41	419	12	32
Lower	59,687	247,293	570,410	0.32	0.41	428	13	31

TABLE 3. (Continued)

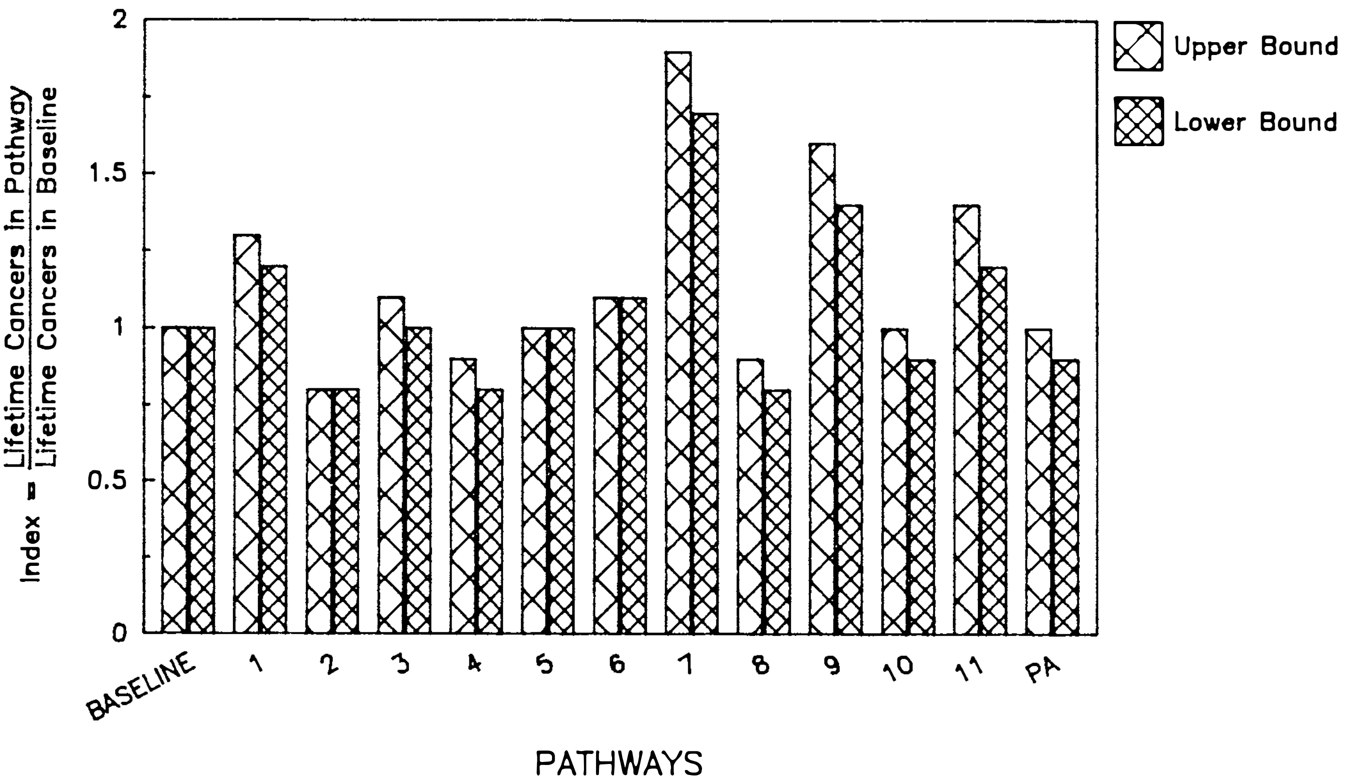
Alternative	New Energy-Efficient Homes(a)	Total Electric Additions(a)	Affected Population	Ventilation Rate, ACH		Rn-Induced Lifetime Cancers/ 100,000 Persons[b]	HCHO-Induced Lifetime Cancers/ 100,000 Persons	Energy Savings, Average Megawatts
				Energy-Efficient Homes	1983 Practice Homes			
Pathway 7								
Upper	59,687	247,293	570,410	0.16	0.41	539	16	33
Lower	59,687	247,293	570,410	0.13	0.41	578	18	32
Pathway 8								
Upper	59,687	247,293	570,410	0.42	0.41	401	12	41
Lower	59,687	247,293	570,410	0.39	0.41	408	12	40
Pathway 9								
Upper	59,687	247,293	570,410	0.20	0.41	495	15	40
Lower	59,687	247,293	570,410	0.17	0.41	526	16	38
Pathway 10								
Upper	59,687	247,293	570,410	0.34	0.41	422	12	40
Lower	59,687	247,293	570,410	0.30	0.41	436	13	39
Pathway 11								
Upper	59,687	247,293	570,410	0.23	0.41	473	14	35
Lower	59,687	247,293	570,410	0.19	0.41	504	15	34
Preferred Alternative								
Upper	59,687	247,293	570,410	N/A	N/A	419	12	34
Lower	59,687	247,293	570,410	N/A	N/A	410	12	35
Environmentally Preferred Alternative								
Upper	59,687	247,293	570,410	0.42	0.41	401	12	41
Lower	59,687	247,293	570,410	0.39	0.41	400	12	40

(a) Total number of manufactured homes projected through 2006.

(b) Lifetime cancer rates include both energy-efficient and baseline homes. The net effect of BPA's activities can be estimated by subtracting the lifetime cancer rate of the Baseline from those of the alternatives.

Preferred Alternative: The estimated number of lifetime cancers due to exposure to radon is similar to the values estimated for the Baseline. Estimates for single-family homes is slightly higher, while estimates for multifamily and manufactured homes are slightly lower.

Environmentally Preferred Alternative: The estimated number of lifetime cancers is lower than estimates for the Baseline. This is consistent with the Pathway's (8) higher ventilation rates.



PA = Preferred Alternative

Figure 1. Health Effects Associated with Pathways

SOCIAL AND ECONOMIC IMPACTS

The primary social and economic impacts are in the areas of fuel choice and energy savings. Fuel choice refers to the decision made by consumers regarding which fuel (electricity or other fuels) they will use to heat their home. If new electrically heated homes are required to be built to energy-efficient standards while homes with other fuel types are not so required, then homes using other fuels could have a lower purchase price than electrically heated homes. However, energy-efficient homes will have lower energy costs over the life of the structure, leading to lower life-cycle costs. Still, the greater first-time costs may induce some consumers to choose natural gas or oil, instead of electricity, to heat new homes.

Baseline: We assumed no energy savings for the Baseline. This is consistent with the assumption that, without New Energy-Efficient Homes Programs, homes in the future are constructed to prevailing building practices.

No Additional Action Alternative: Programs forming this alternative are estimated to result in energy savings of 155 to 171 average megawatts at a cost of $233 million.

The number of households choosing a fuel other than electricity because of an energy-efficiency standard for electrically-heated new homes is given in BPA's 1986 medium growth forecast of new homes. The number of new single-family and multifamily homes built from 1986 through 2006 that choose an alternative fuel instead of using electric space heat is 169,605, or 18% of the Baseline. Paying incentives dampens the effect of what would otherwise occur with only an energy efficiency standard and no incentive.

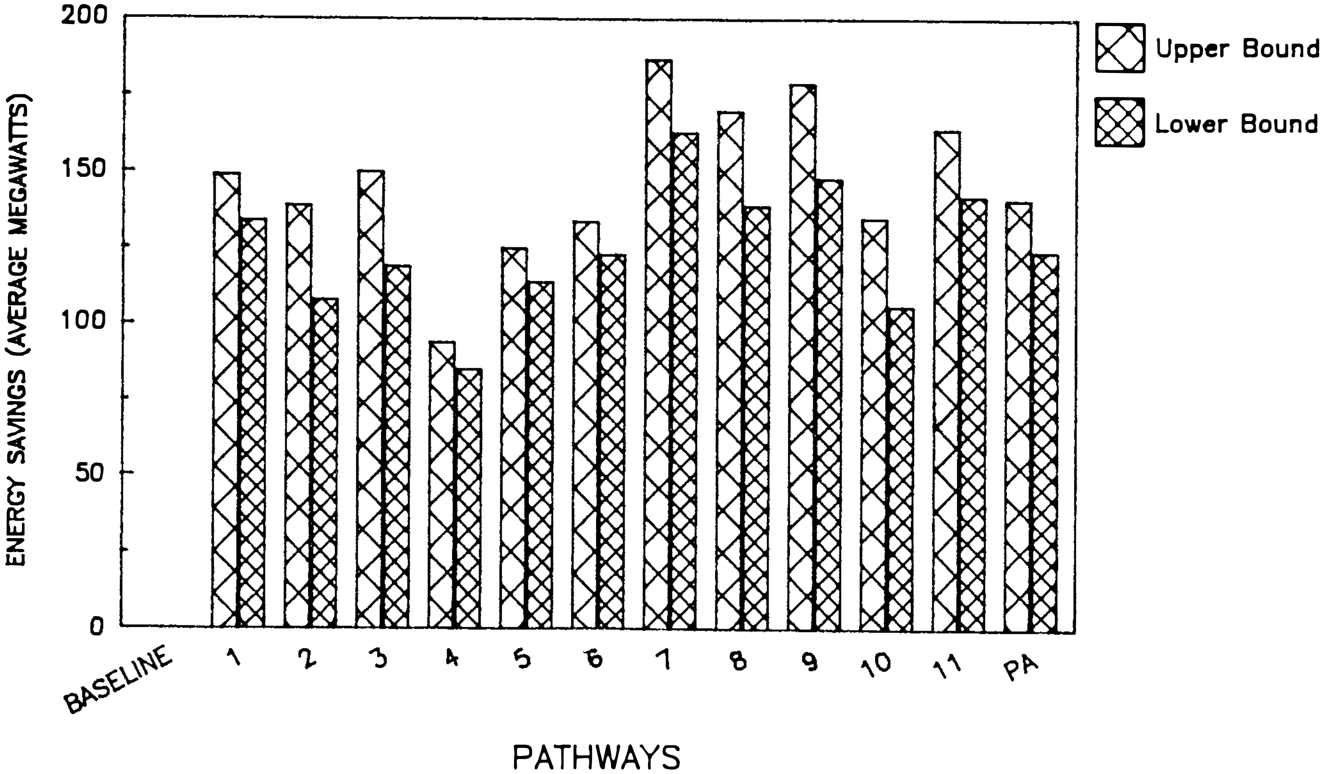
Proposed Action Alternative: For this alternative, estimated energy savings range from a low of 113 average megawatts to a high of 228 average megawatts. Costs range from approximately $229 million to about $522 million. These figures vary with each of the pathways. See Figures 2 and 3 and Tables 1 through 4.

Preferred Alternative: For this alternative, estimated energy savings range from 158 to 165 average megawatts depending on whether the upper or lower bound of the ventilation estimate is used. Expenditures for this alternative are approximately $379 million.

Environmentally Preferred Alternative: For this alternative, estimated energy savings range from 179 to 211 average megawatts, depending on whether the upper or lower bound of the ventilation estimate is used, at a cost of $522 million.

AVOIDED IMPACTS

Avoided impacts refer to environmental consequences that are avoided because electric generating resources are not required to supply the energy that is being supplied through implementation of the New Energy-Efficient Homes programs. Both the Council's resource portfolio and BPA's 1986 resource strategy indicate that small hydropower would be the next resource to be developed if the conservation resource were not acquired. Other potential resources include cogeneration, combustion turbine generators, and coal-fired generators. Some of the avoided impacts of not developing these other resources are summarized in Table 5.



PA = Preferred Alternative

Figure 2. Energy Savings Associated with Pathways

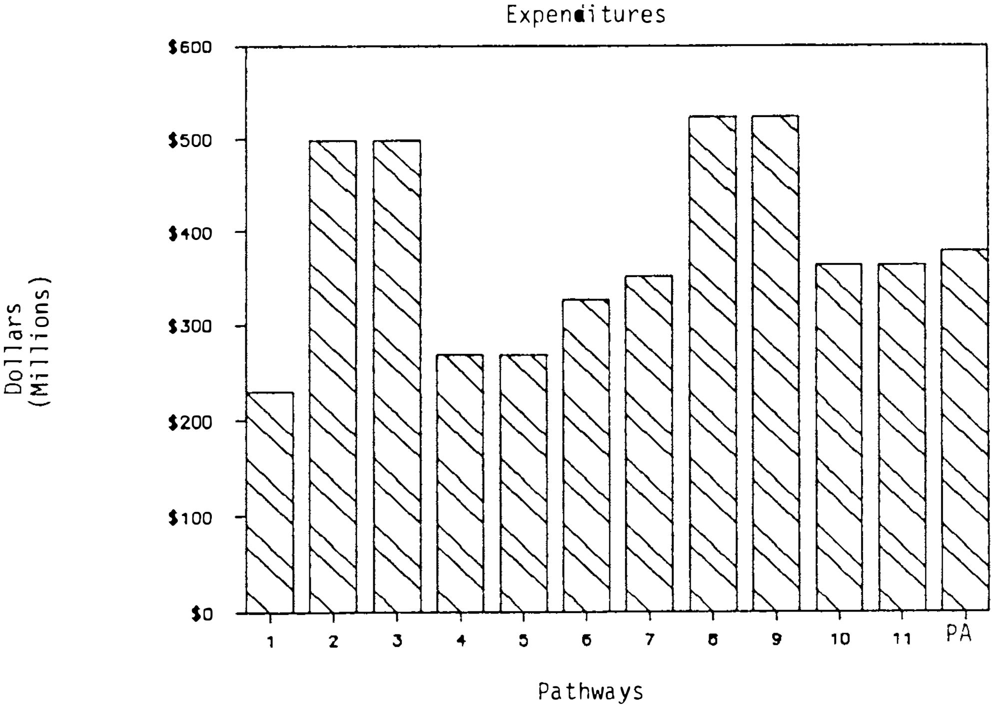


Figure 3. Expenditures Associated with Pathways

TABLE 4. Regional Expenditures of the Alternatives

Alternative	Expenditures (1986 Million $)
No Additional Action	233
Proposed Action Pathways	
1	229
2	497
3	497
4	268
5	268
6	326
7	351
8	522
9	522
10	390
11	390
Preferred Alternative	379
Environmentally Preferred Alternative	522

TABLE 5. Total Avoided Impacts of Alternative Actions[a]

	Small Hydropower	Municipal Solid-Waste Cogeneration	Combustion Turbine	Coal-Fired Plant
No Additional Action				
Public mortality	--	77[b]	0	.40
Public injury and morbidity	--	--	.40	3.4
Solid waste (tons)	0	(c)	Negligible	470,000
Air emissions (tons)	Negligible	7,330	2,176	4,810
Water use/consumption	2.6 M acre-ft	280 M gal	504 acre-ft	1,168 M gal
Land use (acres)	9,050	137	25	229
Proposed Action				
Pathway 4				
Public mortality	--	54[b]	0	.30
Public injury and morbidity	--	--	.30	2.5
Solid waste (tons)	0	(c)	Negligible	345,000
Air emissions (tons)	Negligible	5,292	1,477	3,446
Water use/consumption	2.0 M acre-ft	209 M gal	357 acre-ft	825 M gal
Land use (acres)	8,523	96	17	160
Proposed Action				
Pathway 7				
Public mortality	--	104[b]	0	.55
Public injury and morbidity	--	--	.55	4.7
Solid waste (tons)	0	(c)	Negligible	628,000
Air emissions (tons)	Negligible	9,939	2,930	6,487
Water use/consumption	3.7 M acre-ft	390 M gal	670 acre-ft	1,570 M gal
Land use (acres)	12,555	188	35	314

(a) Baseline not included because no energy savings are assumed. Estimates based on energy savings of site-built homes only.

(b) Mortality and morbidity are combined, based on linear dose response.

(c) Burning solid waste as fuel results in net reduction of solid waste requiring disposal.

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PURPOSE AND NEED

1.0 PURPOSE AND NEED FOR ACTION

The Bonneville Power Administration (BPA) proposes to give builders and consumers considerably more flexibility in its New Energy-Efficient Homes Programs by increasing the options for controlling the quality of indoor air. In doing so, the agency is responding to the underlying need to maintain indoor air quality (IAQ) in new energy-efficient homes that is at least comparable to that found in new homes built to 1983's prevailing construction practices. Thus far, the Program has relied primarily on mechanical ventilation (MV) systems with heat recovery, such as air-to-air heat exchangers (AAHX). However, this policy relies on a fairly restricted approach, and through its Proposed Action BPA suggests that these systems may not always be the best or most practical means of protecting IAQ.

There is considerable debate over these systems, including their costs, their ease of installation, and ultimately their suitability for specific houses and climate zones. In this Environmental Impact Statement (EIS) additional approaches and mitigation measures are examined to see how well they will control IAQ and still maintain cost-effective energy savings.

1.1 BACKGROUND

The proposed New Energy-Efficient Homes Programs will offer a cost-effective means for BPA to meet its obligation to furnish the Pacific Northwest with an adequate, reliable, economical, and efficient electrical energy supply. In 1980 the Pacific Northwest Electric Power Planning and Conservation Act, Public Law 96-501 (the Act), gave BPA the responsibility of acquiring all necessary energy resources to serve Northwest utilities choosing to purchase wholesale electricity from the agency. BPA was directed to give cost-effective conservation highest priority in responding to the demand for electricity.

The Act also led to the creation of the Northwest Power Planning Council (the Council), composed of two members from each of the Pacific Northwest states of Idaho, Montana, Oregon, and Washington. One of the Council's primary responsibilities was to develop a long-term plan for meeting the electrical needs of the Northwest through the identification and acquisition of cost-effective energy resources. Model Conservation Standards (MCS) for the construction of new energy-efficient homes were among the resources to be included in its plan, as specified by the Act. The Act also allows that a surcharge be levied against utilities or local jurisdictions that have failed to implement a program to gain the energy savings from MCS or comparable savings from another program. Utilities not implementing a BPA-approved option by 1 February 1988 will be subject to a 10% surcharge on their residential load.

In developing the 1983 and 1985 Northwest Conservation and Electric Power Plans (the Plan), the Council determined that the region could save energy at a substantially lower cost through the construction of new energy-efficient homes than it could through acquiring similar amounts of power from other resources. The Council further noted that new energy-efficient homes will reduce future load growth in the residential sector; that load growth occurs largely because population growth requires additional housing. If new housing is designed and built to be energy-efficient, there will be less load growth than if the housing is built to prevailing practices, which does not incorporate as many energy conservation measures. The Council also noted that energy-saving features delineated in the MCS will be much more difficult, and thus more expensive, to install after a home is built.

By promoting new energy-efficient homes now, it is expected that, in the future, these homes will represent standard practice. This is an important consideration, given the current electricity surplus and the projected load growth and demand for the region.

As the Council recommended, BPA is currently promoting the construction of energy-efficient homes through various means. These include a marketing program, incentive payments, financial assistance to jurisdictions that incorporate the MCS into their building codes, and implementation of a surcharge policy. One potential environmental effect in these homes is an increased level of indoor air pollutants due to reduced ventilation rates. To date, BPA has avoided or minimized this potential effect in energy-efficient homes in its programs by maintaining ventilation rates found in homes built to 1983 practice through the use of AAHXs or other MV systems. When homes have not been maintained at 1983 ventilation rates, BPA has required radon and formaldehyde monitoring. If radon and formaldehyde levels exceeded guideline concentrations of 5 picocuries per liter (pCi/l) and 0.1 part per million (ppm), respectively, AAHXs were installed.

1.2 PROGRAM GOALS AND PURPOSES

The goals and purposes of the New Energy-Efficient Homes Programs are:

- to achieve consistency with the Act through the reduction of future electrical load growth by adding cost-effective energy conservation features in new homes
- to deliver the programs through existing networks of builders, utilities, local jurisdictions, and code officials
- to minimize potential health effects from energy-saving features built into new energy-efficient homes
- to include in the Programs all practical, commercially available methods that will protect and possibly enhance IAQ in new energy-efficient homes.

ALTERNATIVES INCLUDING THE PROPOSED ACTION

2.0 ALTERNATIVES INCLUDING THE PROPOSED ACTION

This chapter describes and compares the various alternatives, including the Proposed Action, considered by BPA for its New Energy-Efficient Homes Programs. The environmental effects of each alternative are also described and compared. The framework for analyzing the impacts associated with each alternative is based on the most critical environmental issue related to new energy-efficient houses--indoor air quality (IAQ).

The alternatives were determined by the fundamental decision to be explored through this EIS: whether to maintain the current action, which relies on a limited approach for protecting IAQ [i.e., ensuring 0.49 air changes per hour (ACH) through both natural and mechanical ventilation], or to broaden the approach and add other means of protecting IAQ in new energy-efficient houses. Because IAQ is the principal issue for this EIS, the infiltration and ventilation characteristics of the housing associated with each alternative are given in the descriptions of the alternatives, which include:

- Baseline (no BPA actions to acquire the new homes resource)
- No Additional Action (BPA's 1986-87 new homes activities)
- Proposed Action (same as the No Additional Action but with the addition of options to provide flexibility for dealing with IAQ).
- Preferred Alternative (a combination of selected options from the Proposed Action)
- Environmentally Preferred Alternative (option from Proposed Action with the most beneficial environmental effects).

These alternatives are not necessarily exclusive of each other because more than one could be implemented. Questions of cumulative effects of the incremental actions may be pertinent to any decision implemented, and are addressed in the analysis.

In the course of describing the analysis, we refer not only to the new appendixes (A through M) created for this Final EIS, but also to the four appendixes in Vol. II of the DEIS (BPA 1987a), which serve as background information for this document. Because the information in the four appendixes in the DEIS are still current and required no revision of substance, and in order to save government reproduction costs, those appendixes are not reproduced in this Final EIS. Reference to them will always by accompanied by "DEIS" to distinguish them from the appendixes in Vol. II of this Final EIS.

2.1 BASELINE

The Baseline is an artificial construct for the analysis: it is based on the 1986 medium housing forecast (BPA 1986a) and an assumption that the MCS do not exist. It thus assumes no BPA actions to promote energy-efficient homes. This condition drives all the assumptions for the Baseline. For example, without any MCS programs, the penetration rate of energy-efficient homes is assumed to be zero. Because the key concern is IAQ, we must consider how to reflect air exchange rates under this condition.

There is an actual frequency distribution of air change rates per hour for housing built to today's prevailing building practices (hereafter called "current practice,") but it is not known with certainty. Using two different measurement techniques, BPA has been engaged in studies to estimate that unknown distribution. It appears from the literature and from BPA's work in the Residential Standards Demonstration Program (RSDP) that these two techniques result in estimates that probably bound the actual distribution.

One technique, known as fan pressurization testing, uses a blower door to measure an equivalent leakage area (ELA) in the building, which can be thought of as the sum of all the holes and cracks of the building's envelope. This ELA is combined with typical weather conditions and additional assumptions regarding the homes' physical characteristics to estimate an average natural ventilation rate for the heating season. This test is done in an empty house and does not account for effects of occupancy or mechanical ventilation. Bonneville performed this test in some 450 houses representative of 1983 building practice.

Bonneville retested some of these same homes with another technique that uses perfluorocarbon tracer (PFT) gas to estimate total ventilation rates. This test, which was developed by Brookhaven National Laboratory, is conducted over a longer period of time and with people in the house. Because it is a long-term integrated average measurement, it includes the effects of occupants using the house's MV systems, opening doors and windows, and the influence of actual weather conditions, as well as the infiltration rate. However, the result is limited by the fact that it is valid only for the time period and specific weather conditions experienced during the testing period. In addition, the technique relies on measuring the quantity of tracer gas in the house as a consequence of ventilation. The amount of tracer collected during the test in inversely proportional to the actual air change rate. Thus, the ventilation rate estimated by the PFT test is a tracer "dilution rate"; we call this the "effective" ventilation rate, described more fully later in this section.

These two techniques yielded different results within the same house. Fan pressurization tests indicated an average ventilation rate of 0.49 ACH, although, in fact, the levels of air exchange measured in these homes varied widely, ranging from near zero to 2.0 ACH. The PFT tests yielded an average estimate of 0.35 ACH and also varied widely, though not as widely as the fan pressurization results.

The results are different because the tests measure different things. The fan pressurization, or blower door, test is predictive; it estimates leakage only and predicts from that ELA the air exchange rate over some other weather conditions. The PFT test estimates the total ventilation rate that occurred over the testing period; it estimates what the air change was. The

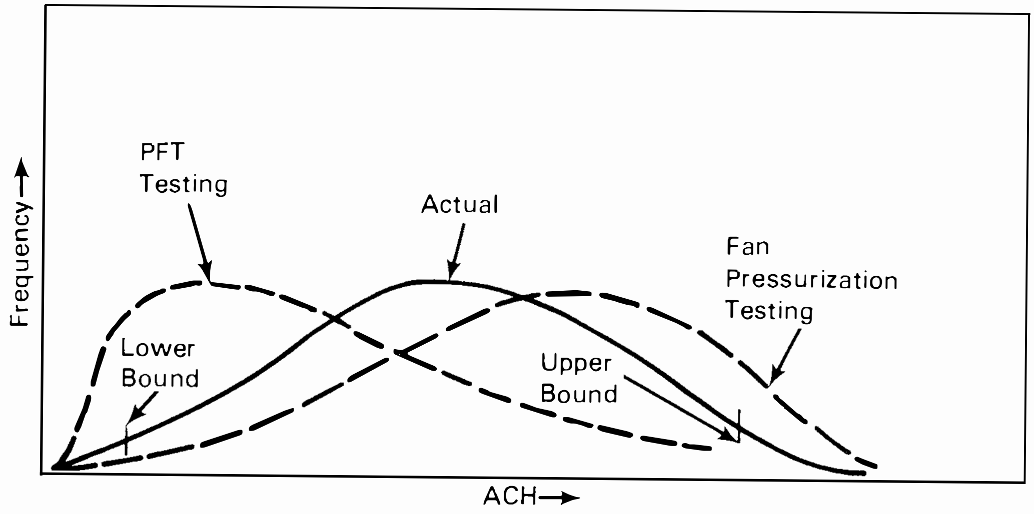


Figure 2.1. Distribution of Air Exchange Rates

techniques are biased in a narrow range, with PFT generally yielding lower estimates and fan pressurization tests giving higher estimates and spanning a broader range (Figure 2.1). However, BPA believes these two tests are representative of the uncertainty of residential ventilation rates and the inability to accurately determine the rate in any particular home.

The uncertainty reflected by these different testing results was compounded by the amount of scatter in the data, which, together, precluded the application of classical statistical techniques. Further, results from these tests, as well as results from other experiments and studies, indicated the unlikelihood of measuring the actual ventilation rate with any certainty. However, we also believe that if we could accurately measure a home's ventilation rate, the result would lie between the results of these two tests.

In the face of this uncertainty, BPA decided to be guided by the previous testing experiences and develop upper and lower bound estimates that most likely define the range of ventilation rates in baseline homes as well as for the alternatives (see Appendix A for a full discussion). These two estimates not only reflect the uncertainty in determining ventilation rates but also provide a range of environmental effects that is linked to the actual distribution of ventilation rates found in homes.

The Baseline therefore is represented by a selected upper and lower ventilation rate estimate against which to compare alternatives. Although it is likely that building practice will improve over time and houses will become more energy-efficient, there is not enough information to reliably estimate how much ventilation rates are likely to decrease or over what period of time. For purposes of our analysis, we have therefore assumed constant ventilation rates for the full 20-year planning period. The average upper bound for single-family homes is assumed to be 0.49 ACH; the average lower bound is given at 0.38 ACH.

In addition to the average ventilation rates, which are a measure of the average total amount of air moving through the building as a result of both natural forces and mechanical systems, BPA calculated "effective" ventilation rates (see Appendix A). The average ventilation rate is used to calculate heat loss due to infiltration and is thus important for assessing the energy savings for each of the alternatives. However, it does not sufficiently account for the behavior of pollutants over time, and this is what is important in estimating the health effects of indoor air pollutants. The effective ventilation rates represent a more accurate measure of the amount of ventilation that is effective for diluting pollutants; they also better account for the fairly standard theoretical expectation that, for a particular source term, the pollutant concentration will be inversely proportional to the number of air changes per hour. This inverse relationship explains why the effective ventilation rates are always slightly lower than the average ventilation rate (see Table 2.1).

2.2 NO ADDITIONAL ACTION ALTERNATIVE

The No Additional Action Alternative consists primarily of BPA's 1986 activities to promote energy-efficient new homes (BPA 1986b). Three major programs were established to promote such houses: Super GOOD CENTS (SGC), Early Adopters to encourage code adoption of the MCS, and a research and demonstration program to encourage the use of advanced energy-efficient construction techniques (BPA 1986b). For analysis of this alternative, BPA has assumed that by 2006 a 75% penetration rate for MCS houses has been achieved; that is, 75% of new electrically heated houses would meet MCS.

Super GOOD CENTS (SGC) is based on a nationwide utility promotion program for energy-efficient new homes. BPA bought the rights to this program and made it available to utilities, who work with builders, realtors, lenders, and code officials to achieve the construction, certification, and sale of MCS homes in their respective service areas. BPA supplies technical and sales training, cooperative advertising funds, a regional marketing campaign, and information on IAQ and the steps builders and occupants might take to protect it. The program also includes financial incentives, declining over time, to encourage greater participation and to reduce builder costs associated with learning to construct houses that meet the MCS. The goal is to bring current regional building practices up to MCS levels so that energy-efficient codes can be enacted throughout the region.

That goal is also reflected in the Residential Construction Demonstration Project, a project to test innovative construction methods and products. During each cycle of the project, houses built to SGC specifications will have incorporated at least one specified innovation to test their reliability, cost-effectiveness, and marketability. Builders are eligible for technical and financial assistance under this project.

TABLE 2.1. Pathways for Single-Family Homes

							Total Ventilation Rate, ACH	
Pathway	Infiltration Control(a)	Range of Infiltration Rates, ACH		MV System	MV Operation(d)	MV Rate, ACH	Average	Effective
1	Standard	Upper	.32	None	NA	.00	.35	.32
		Lower	.32			.00	.28	.26
2	Standard	Upper	.32	MVHR(c)	Continuous	.19	.53	.52
		Lower	.32			.19	.47	.45
3	Standard	Upper	.32	MVHR(c)	Intermittent	.05	.41	.37
		Lower	.32			.05	.35	.31
4	Standard	Upper	.35	Exhaust	Continuous	.10	.48	.45(b)
		Lower	.25			.10	.40	.38
5	Standard	Upper	.35	Exhaust	Intermittent	.03	.42	.38(b)
		Lower	.25			.03	.34	.31
6	Standard	Upper	.32	Exhaust	Intermittent	.03	.38(e)	.35(b)
		Lower	.32			.03	.31	.29
7	Advanced	Upper	.17	None	NA	.00	.18	.17
		Lower	.17			.00	.15	.14
8	Advanced	Upper	.17	MVHR(c)	Continuous	.26	.43	.43
		Lower	.17			.26	.40	.40
9	Advanced	Upper	.17	MVHR(c)	Intermittent	.04	.27	.21
		Lower	.17			.04	.23	.18
10	Advanced	Upper	.21	Exhaust	Continuous	.13	.34	.34(b)
		Lower	.21			.13	.31	.30
11	Advanced	Upper	.21	Exhaust	Intermittent	.03	.26	.24(b)
		Lower	.21			.03	.22	.20

(a) Standard = Minimum MCS construction for air leakage control; advanced = continuous air barrier.

(b Because the building behaves differently with an exhaust ventilation system than with an AAHX, natural and mechanical ventilation do not sum directly for a total effective ventilation rate.

(c) MVHR = Mechanical ventilation system with heat recovery, or air-to-air heat exchanger.

(d) Continuous = 24 hours/day; intermittent = 8 hours/day.

(e) Pathway 6 does not include ports; therefore the ventilation rate is different from Pathway 5.

The Early Adopter Program, designed to encourage the adoption, implementation, and enforcement of the MCS as code, is aimed at developing the skills needed to implement that objective. Under this program, financial commitments have been allocated for assistance and financial incentives to those jurisdictions that adopt the MCS, either as building codes or as legally enforceable utility service requirements. To offset the higher construction costs of MCS homes, BPA will also continue to provide incentive payments to builders or home buyers in these jurisdictions for each house built.

The No Additional Action Alternative is a combination of two of the options under the Proposed Action (Pathways 5 and 8, which are described below). It was thought that implementation of these two pathways would provide IAQ equivalent to, or better than, IAQ in baseline homes. The premise of this Alternative has been to obtain energy savings from new homes but avoid any increase in adverse health effects relative to 1983 building practice. The implementation strategies for the programs in this Alternative would ensure that IAQ and health effects are not worse than what they would be under the Baseline. That has always been the intention of the programs composing this Alternative and is reflected in the IAQ options permitted in these programs.

All homes will have some form of whole-house mechanical ventilation to increase the likelihood that homes will not have ventilation rates below the average targeted rate. All homes will have a minimum level of ventilation to handle moisture, odors, and stale air; that level is 10 cubic feet of outside air per minute (cfm) for each bedroom and one central area. Examples of implementation of the nonheat recovery options are described and illustrated in Appendix M. Houses with continuous air barriers will also have central heat recovery ventilation, typically an AAHX. In all cases, the programs' components are designed to achieve the same average air changes as homes built to 1983 practice. Thus, this alternative was analyzed with average air exchange rates for energy-efficient houses that are the same as the Baseline: an upper bound of 0.49 ACH and lower bound of 0.38 ACH.

2.3 PROPOSED ACTION

Under the Proposed Action, BPA would continue all of its new homes programs as designed in 1986 (No Additional Action); thus, the penetration rate and resulting estimate of MCS homes built will be the same as that for the No Additional Action. However, a broad menu of options, or pathways, to provide some flexibility for dealing with IAQ is proposed.

Mechanical ventilation with heat recovery (e.g., an AAHX) may not always be the best or most practical solution for controlling IAQ in energy-efficient houses; other control devices or mitigation strategies may be equally effective, as well as less expensive, in certain situations. Thus, BPA proposes to add all practical, commercially available methods to maintain acceptable IAQ and still obtain energy savings in its New Energy-Efficient Homes Programs, giving builders and consumers considerably more flexibility.

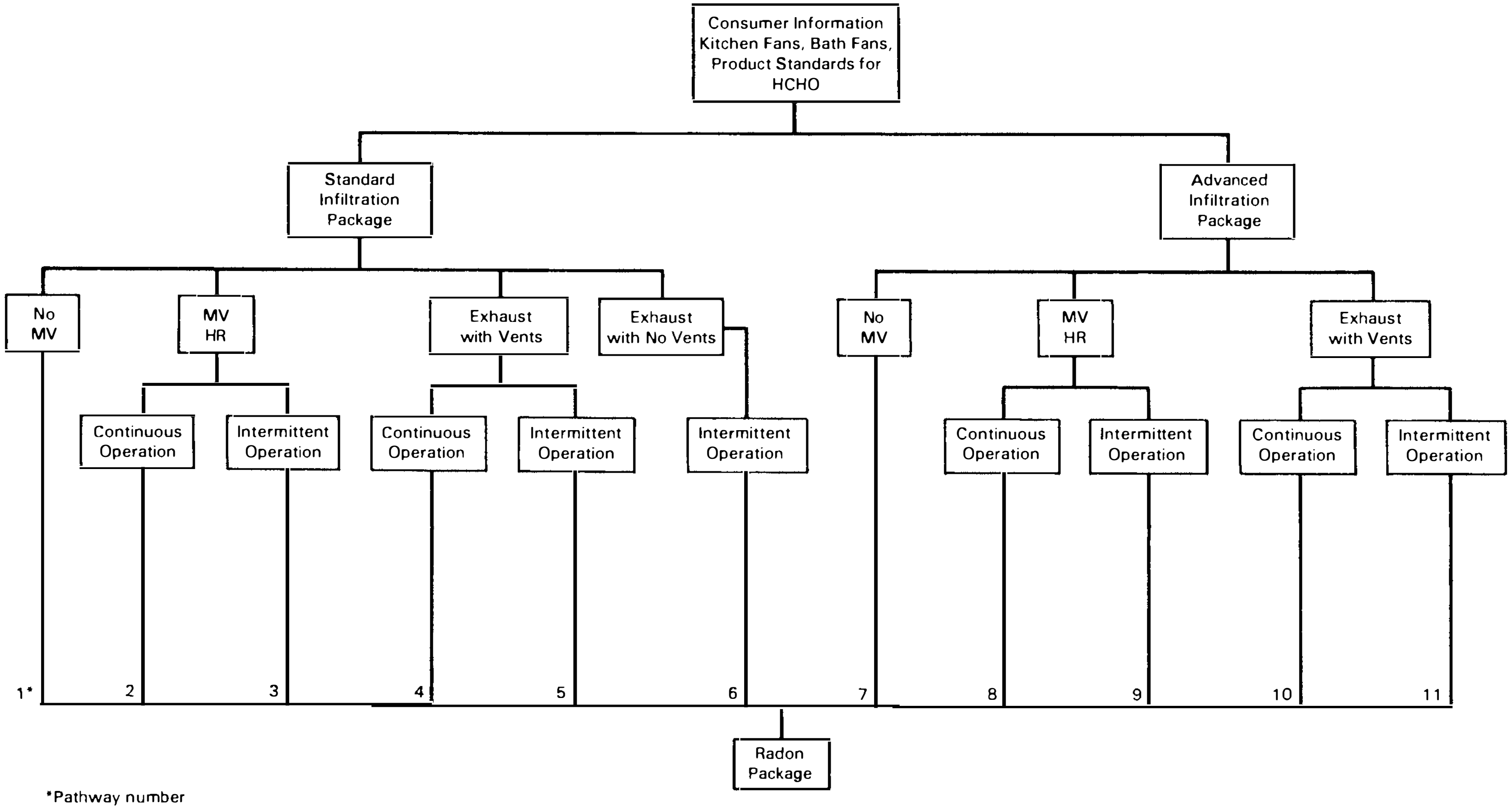
A number of strategies were delineated to form pathways (Table 2.1) that might meet these criteria. Referring to Figure 2.2, note that all pathways share the following minimum requirements: consumer information on IAQ; exhaust fans for kitchen and bathrooms; outside air supply for combustion appliances; HUD product standards to reduce formaldehyde; and a radon package. The health benefits derived from this standard package of IAQ requirements accrue to all of the pathways. Beyond this common set of requirements, each pathway has different components and therefore different ventilation rates.

The radon package allows a builder one of two basic approaches (Figure 2.3): 1) either the builder constructs the house to include certain preconstruction source control measures (i.e., a ventilated crawlspace and/or a layer of gravel under the concrete slab) and the occupant has the option of monitoring, or 2) the builder forgoes installing those measures used to reduce radon levels and is then required to monitor radon levels. If monitoring shows that radon levels exceed 5 pCi/l, then the builder will be required to retrofit the house with the appropriate mitigation measure, and activate the measure to reduce the concentrations. For purposes of analysis we assume that such mitigation will reduce radon concentrations by 70%. From a regional perspective a 70% reduction will lower radon concentrations to 5 pCi/l or less in all but about 3% of the homes in the Northwest (BPA 1986c). The radon package is more fully described in Appendix H. Bonneville is using 5 pCi/l for an action level as a result of the BPA Expanded Weatherization Environmental Impact Statement. Documentation can be found in the Record of Decision for that document.

The pathways are structured around three key variables: the infiltration control applied to the house; the MV system; and the occupants' operation of the MV system. The residences analyzed in the pathways are of two types depending on their approach to infiltration control. There is the standard approach, which includes houses that are well-sealed with caulking and weatherstripping; or builders may take a more advanced approach to air leakage control by installing a continuous air barrier. These residences have considerably lower average air leakage rates (0.17 ACH versus 0.32 ACH for single family houses with standard infiltration control).

There are four basic choices regarding MV systems. A house can be without a whole-house MV system ; a house can have central mechanical ventilation with heat recovery (e.g., an AAHX); it can have a central mechanical exhaust ventilation system with openings for outside air supply; and it can have a central mechanical exhaust system without openings for outside air (this choice is not allowed for houses with advanced air infiltration control). The three basic MV systems are sized to provide different capacities. A more thorough discussion of these and other MV systems and mitigation technologies is included in the DEIS, Vol. II, Appendix C (BPA 1987a) and in Appendix M to this Final EIS (Vol. II).

Two operating or control options that represent the amount of time the MV system operates are analyzed. A continuously operating (24 hr) MV system represents the ideal situation that results in a controlled, constant rate of air exchange. The other option is intermittent operation and assumes the system operates 8 hr/day. Besides the intermittent control devices used today, the second option acts as a proxy in the analysis for control



*Pathway number

Figure 2.2. Pathways of the Proposed Action Alternative

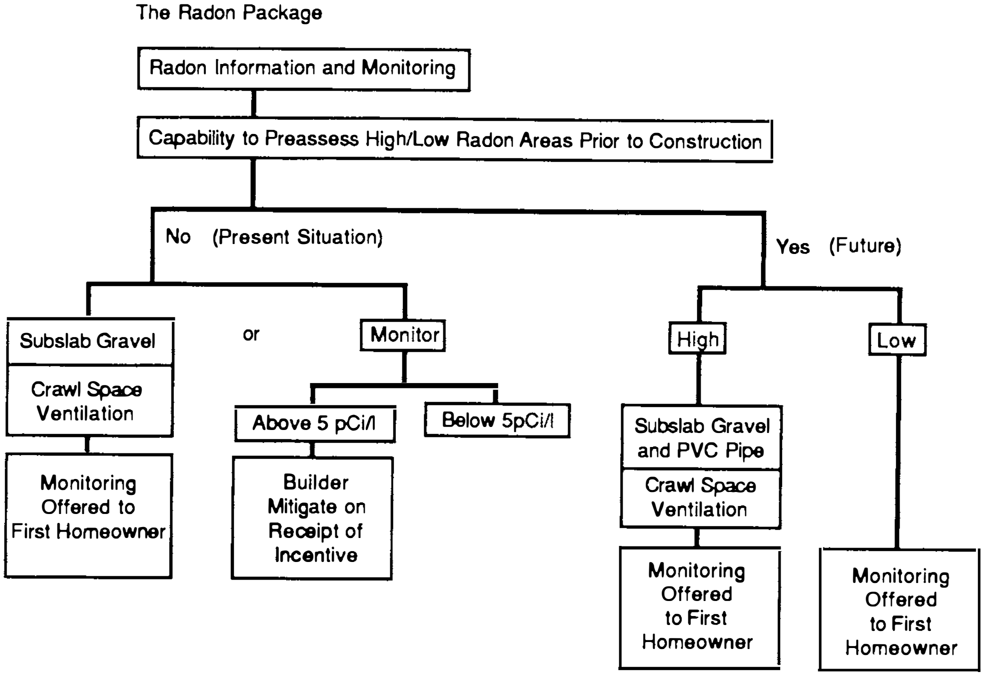


Figure 2.3. Radon Package

technologies that are not widely available and used today but that are likely to be commonplace in new homes within the planning period covered by this document (1986-2006); these controls would be triggered by such things as outdoor temperature and indoor pollutant levels.

These three key variables were examined in combination to develop ventilation rates. All of the mitigation strategies are embodied in these ventilation rates, and combine into 11 distinct pathways which comprise the Proposed Action Alternative, presented in detail in Table 2.1. As shown in the table, there are average upper and lower bound ventilation rates for each pathway. Tables 2.2 and 2.3 show the same information for multifamily and manufactured homes. These ventilation rates are the driving variable for the analyses of the 11 pathways, which are summarized below. These descriptions of the pathways are general in nature and do not include detailed specific strategies or costs for implementing the various pathways. The EIS does not develop specifications for implementing the pathways in order to maintain the flexibility of allowing new technologies which meet criteria considered in this EIS.

Referring to Figure 2.2 (and Table 2.1) will help the reader to distinguish among the pathways and better follow this description of pathways. For example, the figure illustrates obvious pairings between Pathways 2 and 3; between 4 and 5; between 8 and 9; and between 10 and 11. It also clearly

TABLE 2.2. Pathways for MultiFamily Homes

Pathway	Infiltration Control(a)	Range of Infiltration Rates, ACH		MV System	MV Operation(d)	MV Rate, ACH	Total Ventilation Rate, ACH	
							Average	Effective
1	Standard	Upper	.20	None	NA	.00	.21	.19
		Lower	.20			.00	.16	.15
2	Standard	Upper	.20	MVHR(c)	Continuous	.26	.46	.45
		Lower	.20			.26	.41	.40
3	Standard	Upper	.20	MVHR(c)	Intermittent	.05	.29	.24
		Lower	.20			.05	.24	.20
4	Standard	Upper	.25	Exhaust	Continuous	.23	.48	.47(b)
		Lower	.25			.23	.42	.42
5	Standard	Upper	.25	Exhaust	Intermittent	.05	.34	.29(b)
		Lower	.25			.05	.27	.24
6	Standard	Upper	.20	Exhaust	Intermittent	.05	.29	.24(b)
		Lower	.20			.05	.23	.19
7	Advanced	Upper	.12	None	NA	.00	.13	.12
		Lower	.12			.00	.12	.11
8	Advanced	Upper	.12	MVHR(c)	Continuous	.26	.38	.37
		Lower	.12			.26	.37	.36
9	Advanced	Upper	.12	MVHR(c)	Intermittent	.04	.21	.15
		Lower	.12			.04	.20	.14
10	Advanced	Upper	.17	Exhaust	Continuous	.25	.42	.41(c)
		Lower	.17			.25	.40	.40
11	Advanced	Upper	.17	Exhaust	Intermittent	.04	.26	.21(c)
		Lower	.17			.04	.24	.19

(a) Standard = Minimum MCS construction for air leakage control; advanced = continuous air barrier.

(b Because the building behaves differently with an exhaust ventilation system than with an AAHX, natural and mechanical ventilation do not sum directly for a total effective ventilation rate.

(c) MVHR = Mechanical ventilation system with heat recovery, or air-to-air heat exchanger.

(d) Continuous = 24 hours/day; intermittent = 8 hours/day.

TABLE 2.3. Pathways for Manufactured Homes

Pathway	Infiltration Control(a)	Range of Infiltration Rates, ACH		MV System	MV Operation(d)	MV Rate, ACH	Total Ventilation Rate, ACH	
							Average	Effective
1	Standard	Upper	.29	None	NA	.00	.35	.31
		Lower	.29			.00	.32	.29
2	Standard	Upper	.29	MVHR(c)	Continuous	.21	.55	.53
		Lower	.29			.21	.51	.50
3	Standard	Upper	.29	MVHR(c)	Intermittent	.05	.43	.36
		Lower	.29			.05	.39	.34
4	Standard	Upper	.32	Exhaust	Continuous	.12	.49	.46(b)
		Lower	.32			.12	.46	.43
5	Standard	Upper	.32	Exhaust	Intermittent	.03	.42	.38(b)
		Lower	.32			.03	.39	.35
6	Standard	Upper	.29	Exhaust	Intermittent	.03	.39	.35(b)
		Lower	.29			.03	.36	.32
7	Advanced	Upper	.13	None	NA	.00	.18	.16
		Lower	.13			.00	.15	.13
8	Advanced	Upper	.13	MVHR(c)	Continuous	.26	.42	.42
		Lower	.13			.26	.40	.39
9	Advanced	Upper	.13	MVHR(c)	Intermittent	.04	.27	.20
		Lower	.13			.04	.23	.17
10	Advanced	Upper	.16	Exhaust	Continuous	.14	.35	.34(b)
		Lower	.16			.14	.31	.30
11	Advanced	Upper	.16	Exhaust	Intermittent	.03	.26	.23(b)
		Lower	.16			.03	.23	.19

(a) Standard = Minimum MCS construction for air leakage control; advanced = continuous air barrier.

(b Because the building behaves differently with an exhaust ventilation system than with an AAHX, natural and mechanical ventilation do not sum directly for a total effective ventilation rate.

(c) MVHR = Mechanical ventilation system with heat recovery, or air-to-air heat exchanger.

(d) Continuous = 24 hours/day; intermittent = 8 hours/day.

shows the first division of distinction: the first six pathways all have the standard infiltration control package; the last five all rely on the advanced approach (continuous air barrier).

- Pathway 1: This pathway applies to well-sealed, energy-efficient houses that do not have air barriers as one of the conservation measures. This standard approach refers to minimum MCS construction standards for air leakage control. Like the original "Package A" home in the Council's 1983 Plan (NWPPC 1983, vol.II, Appendix J, p.J-51), this pathway has no central MV system, relying only on exhaust fans for spot ventilation. Since incidental mechanical ventilation is not included in the calculation of the total ventilation rates, the average rates are the same as the design ventilation rates of well-sealed houses without air barriers: 0.35 ACH for upper bound and 0.28 ACH for lower bound.

- Pathway 2: This pathway also applies to houses with standard infiltration control, but whole-house, balanced mechanical ventilation, operating continuously, is sized to give average ventilation levels equivalent to, or greater than, 1983 practice (0.53 and 0.47 ACH for upper and lower values, respectively). Wall- or window-mounted balanced MV devices may be used, but several may be needed to achieve a "whole-house" effect. This represents the houses built in the RSDP.

- Pathway 3: This is the counterpart to Pathway 2. Everything is the same, except that the MV system operates intermittently, for a total of 8 hr per day instead of 24. This intermittent operation results in lower average ventilation rates than Pathway 2 (0.41 and 0.35 ACH for upper and lower values, respectively).

- Pathway 4: In this pathway, the standard infiltration control is combined with a central exhaust MV system, instead of an AAHX, with intakes to supply makeup air. The system is operated continuously and provides average ventilation rates of 0.48 ACH and 0.40 ACH.

- Pathway 5: This pathway represents the 1987 SGC basic home and the illustrative prescriptive path for the Council's 1987 MCS. It is identical to Pathway 4, except for intermittent operation of the MV system. The intake ports provide the makeup air to give a pressure-balanced system; they also provide better distribution of the makeup air because of their placement. Because the MV system is operated only 8 hr/day, this pathway results in lower ventilation rates (0.42 ACH for upper bound and 0.34 for the lower bound).

- Pathway 6: This pathway is a variant of Pathway 5; its primary difference is the absence of intake ports for makeup air supply, which results in an unbalanced system and ventilation values of 0.38 and 0.31 ACH for upper and lower bounds. The fan required for this pathway would have a higher capacity than that required in Pathway 5, because the exhaust side will require ducting to at least four points from which to draw air. Because ports are not required in this pathway, a diagnostic blower door test will be required for every house built under this pathway to verify that a minimum ELA is obtained. If the test indicates that the house's ELA is below what would be necessary for the fan's capacity, then ports would be added to provide the requisite makeup air capacity.

- Pathway 7: This pathway applies to houses that take the advanced approach to infiltration control by installing a continuous air barrier but do not include MV systems. Therefore, no ventilation is added to the natural infiltration rate, resulting in the lowest ventilation rates--upper value of 0.18 ACH and lower value of 0.15 ACH.

- Pathway 8: This pathway includes continuously operating, whole-house, balanced mechanical ventilation in energy-efficient houses built with air barriers. This pathway represents the original Package B home in the Council's 1983 Plan (NWPPC 1983, vol. II, Appendix J, p.J-51); it is also included in the No Additional Action Alternative in this Final EIS. Even with the air barrier, the continuously operating AAHX provides ventilation equivalent to the Baseline--upper and lower values of 0.43 and 0.40 ACH respectively.

- Pathway 9: This pathway is identical to Pathway 8 except the AAHX operates intermittently and thus results in significantly lower ventilation rates--0.27 and 0.23 ACH.

- Pathway 10: Pathway 10 consists of advanced air leakage control and a whole-house exhaust MV system operating continuously. Although the technology for an automatic continuously operating exhaust system is available and is in use in Europe, it has not yet been widely introduced in the U.S., but may be in the future. The pathway thus represents an option for the future that is encompassed by the 20-year planning period. Its ventilation rates range from 0.34 to 0.31 ACH.

- Pathway 11: This is identical to Pathway 10 except the exhaust MV system operates only 8 hr/day, resulting in lower ventilation rates, which range from 0.26 to 0.22 ACH.

Bonneville has chosen to present the extremes as well as the options more typical of the norm in order to bound the range of potential impacts. While some pathways appear extreme, they all fall within the bounds of reality and completely frame the range of reasonable possibilities. The assumptions and calculations associated with the 11 pathways are given in Chapter 4 and Appendix A.

2.4 SUMMARY OF ENVIRONMENTAL IMPACTS

The alternatives described above and analyzed for this EIS have impacts related to health, regional socioeconomics, energy savings, and "avoided" impacts. The various alternatives can usefully be ranged against baseline conditions to better compare the impacts of each alternative, which are summarized here and given in greater detail in Chapter 4.

Note that these are comparative effects. This is a particularly important distinction given the uncertainty that surrounds most of the issues analyzed in this EIS. This was particularly evident when trying to determine ventilation rates in existing houses (as discussed in section 2.1). Because the confidence interval for any ventilation estimate is already large, then the interval will also be large in the estimated or predicted values for houses built in the future, as in our estimates for the pathways. Another source of uncertainty in the analysis is in the model to estimate the incidence of lung cancer due to decreased ventilation rates. Each value used in the model has a margin of uncertainty associated with it; the cumulative effect may reduce the accuracy of its results.

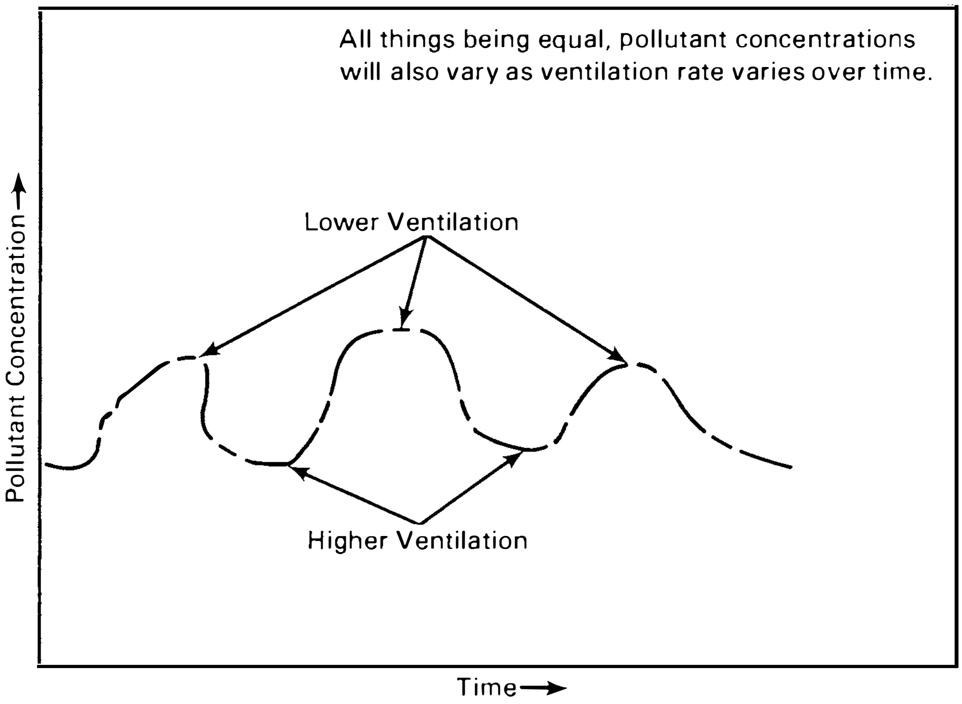
Thus, the numbers in the tables should be regarded as relative, not absolute. We can ascertain the relative consequences of the various alternatives and rank them. And, although the uncertainty surrounding the various inputs into the analysis makes it difficult to quantify how much better one pathway is than another, there is enough information that even when some of the contingencies play themselves out and thus change the absolute numbers, the ranking of the alternatives and pathways will be the same. For more information on uncertainty in reported data, see Appendix L in Vol. II.

2.4.1 Ventilation and Concentrations

The most important potential environmental effect brought about by the Proposed Action is reduced ventilation rates in new homes, and the possible accompanying increased levels of indoor air pollutants. The primary concern identified for the New Energy-Efficient Homes Programs is the effect of these pollutant levels on the health of the occupants. Such pollutants include radon, formaldehyde, combustion gases, respirable suspended particulates (RSP) such as from tobacco smoke, household chemicals, and moisture. We focus on these pollutants because they are commonly found indoors, and they have effects ranging from short-term discomfort to possible occurrence from lung cancer.

The assessment treats some of the pollutants quantitatively and some qualitatively. Radon and formaldehyde are treated quantitatively because there are established risk factors for them, making it possible to quantify the incidence of lifetime cancer rates (per 100,000 persons). Our analysis of these health effects is based on the inverse relationship between ventilation and pollutant levels (see Section 4.1.2). This relationship generally holds true for most pollutants, but not for radon; radon concentrations depend on a more complex set of factors. These include the soil gas concentration, soil permeability, the effective permeability of the interface between the house and soil, the pressure difference between the inside and outside of the house, the distribution of the leakage paths in the house, and the dilution rate (ventilation) in the house. More discussion of the specific relation of radon concentrations to ventilation, and why our analysis does not incorporate this complex set of factors, is given in Appendix B.

We recognize that, for radon, the key issue is entry into the residence and not just ventilation and that the radon gas' source strength can overwhelm



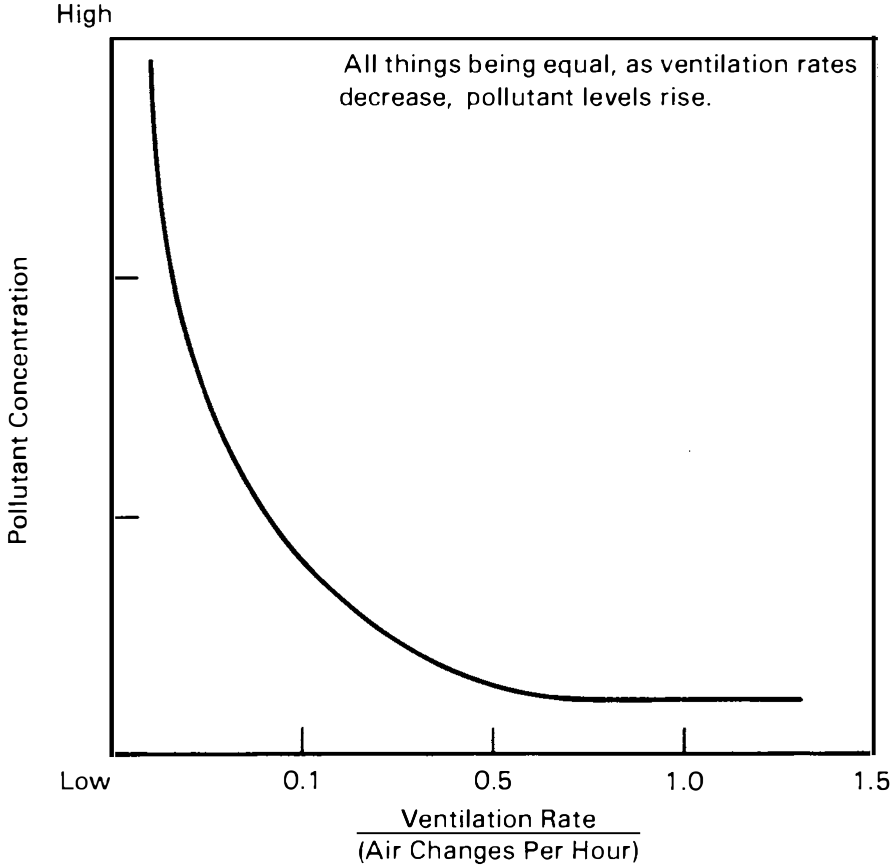


Figure 2.4. Ventilation and Indoor Air Quality

ventilation. However, for an individual house, once radon has entered it, ventilation becomes a key variable in removing it or diluting its effect, as explained in Appendix B. The fact that ventilation varies over time, as illustrated in Figure 2.4a, has been factored into our estimates of "effective" ventilation rates (see Appendix A), which are used to assess the health effects of the Baseline and alternatives. That assessment is based on the relationship between pollutant concentration and ventilation rate as illustrated in Figure 2.4b.

2.4.2 Health Effects From Radon and Formaldehyde

Using a range representative of the actual distribution of ventilation rates, potential lifetime cancers from exposure to radon and formaldehyde were estimated for both the upper and lower values of that range, and compared for the Baseline and alternatives. The impacts of the Baseline, which assumes all homes are built to 1983 practice through 2006, are compared to impacts of the alternatives in Tables 2.4, 2.5, 2.6, for single-family, multifamily, and manufactured homes, respectively. Estimated cancer rates from exposure to radon range from 277 lifetime cancers per 100,000 persons (lower bound of Pathway 2) in single-family houses to 629 lifetime cancers per 100,000 persons (upper bound of Pathway 7). These values correspond to a program in which all homes either have only standard infiltration control measures and a continuous exhaust MV system or have air barriers and no mechanical ventilation. The cancer rate per 100,000 persons ranges from 203 to 599 in multifamily homes, and from 384 to 578 in manufactured homes. The tables also illustrate that the health effects from formaldehyde (HCHO) are minor compared to radon.

This information is also graphically displayed in Figure 2.5, in which impacts are normalized and the Baseline has a value of 1.0. For example, the cancer rate for Pathway 4 is 0.9, or 90%, of the Baseline's value. This means that IAQ measures have reduced the estimated cancer rate to a value below that estimated to occur in the absence of BPA's New Energy-Efficient Homes Programs.

It is instructive to compare these estimates of risk of contracting lung cancer from exposure to radon to other risks. For example, assuming exposure occurs over a lifetime, exposure to 5 pCi/l of radon is equivalent to the risk of developing lung cancer from smoking a little more than one cigarette per day for about 50 years; or equivalent to the risk of a fatal accident from driving 625,000 miles in an automobile.

2.4.3. Other Health Effects

Short-term or acute health effects have not been identified for radon. This may be because short-term impacts from radiological sources are the result of very large amounts of radiation exposure over very short periods of time. Since the level of radon found in most homes is very low, these types of effects would not be expected.

TABLE 2.4. Environmental Impacts of the Alternative Actions Associated with Single-Family Dwellings

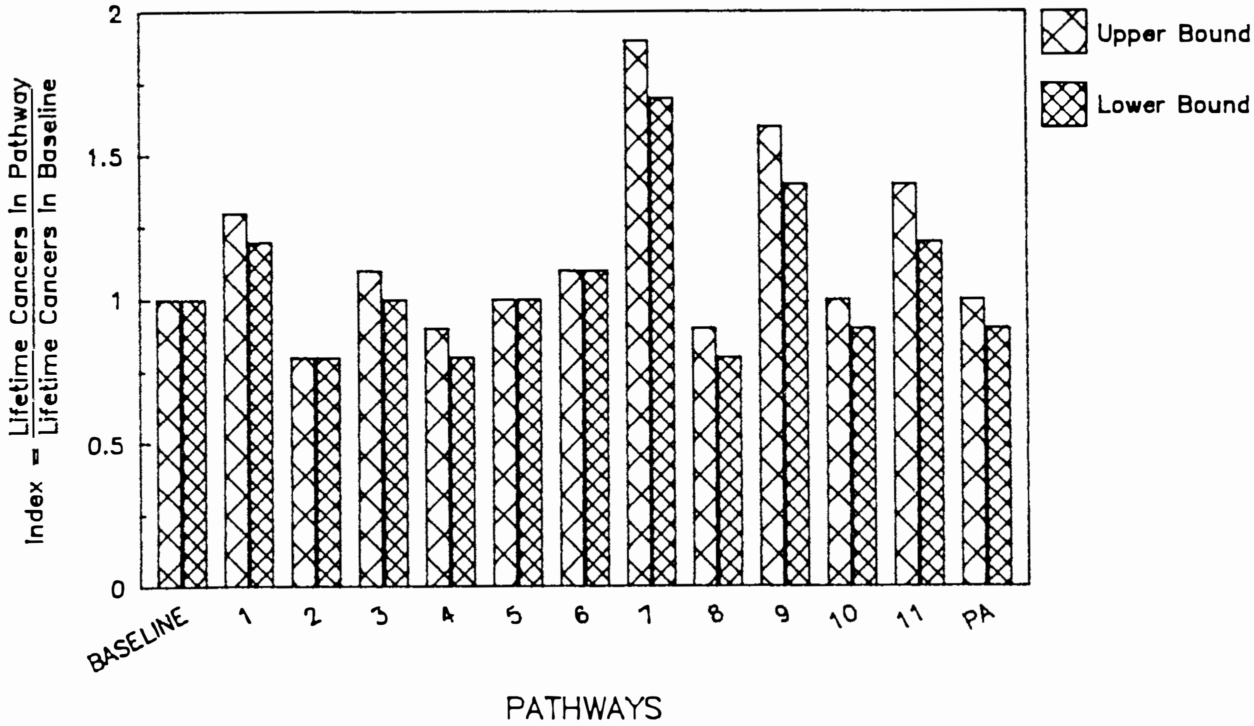
Alternative	Rn Cancers/ 100,000 Persons	HCHO Cancers/ 100,000 Persons	Energy Savings, Avg. MW
Baseline			
Upper	335	10	0
Lower	335	10	0
No Additional Action			
Upper	335	10	104
Lower	335	10	97
Proposed Action			
Pathway 1			
Upper	396	12	113
Lower	385	12	107
Pathway 2			
Upper	293	9	107
Lower	277	8	87
Pathway 3			
Upper	360	11	115
Lower	343	11	95
Pathway 4			
Upper	319	10	78
Lower	304	9	74
Pathway 5			
Upper	354	11	97
Lower	343	11	93
Pathway 6			
Upper	373	12	105
Lower	358	11	99
Pathway 7			
Upper	629	20	148
Lower	601	19	134
Pathway 8			
Upper	328	10	134
Lower	295	9	114
Pathway 9			
Upper	537	17	140
Lower	499	16	120
Pathway 10			
Upper	381	12	113
Lower	351	11	99
Pathway 11			
Upper	486	15	131
Lower	462	14	119
Preferred Alternative			
Upper	352	11	111
Lower	332	10	100
Environmentally Preferred Alternative			
Upper	328	10	134
Lower	295	9	114

TABLE 2.5. Environmental Impacts of the Alternative Actions Associated with Multifamily Dwellings

Alternative	Rn Cancers/ 100,000 Persons	HCHO Cancers/ 100,000 Persons	Energy Savings, Avg. MW
Baseline			
Upper	306	12	0
Lower	306	12	0
No Additional Action			
Upper	306	12	28
Lower	306	12	21
Proposed Action			
Pathway 1			
Upper	419	16	36
Lower	371	15	27
Pathway 2			
Upper	240	9	32
Lower	208	8	21
Pathway 3			
Upper	355	14	35
Lower	306	12	24
Pathway 4			
Upper	235	9	16
Lower	203	8	11
Pathway 5			
Upper	312	12	28
Lower	273	11	21
Pathway 6			
Upper	355	14	29
Lower	316	12	24
Pathway 7			
Upper	599	24	39
Lower	466	18	29
Pathway 8			
Upper	268	11	36
Lower	218	9	25
Pathway 9			
Upper	502	20	39
Lower	390	15	26
Pathway 10			
Upper	253	10	22
Lower	206	6	13
Pathway 11			
Upper	390	15	33
Lower	316	12	23
Preferred Alternative			
Upper	304	12	30
Lower	260	10	24
Environmentally Preferred Alternative			
Upper	268	11	36
Lower	218	9	25

TABLE 2.6. Environmental Impacts of the Alternative Actions Associated with Manufactured Housing

Alternative	Rn Cancers/ 100,000 Persons	HCHO Cancers/ 100,000 Persons	Energy Savings, Avg. MW
Baseline			
Upper	413	12	0
Lower	413	12	0
No Additional Action			
Upper	413	12	39
Lower	413	12	37
Proposed Action			
Pathway 1			
Upper	432	13	37
Lower	440	13	36
Pathway 2			
Upper	384	11	35
Lower	388	11	34
Pathway 3			
Upper	416	12	35
Lower	422	12	33
Pathway 4			
Upper	394	11	37
Lower	399	12	35
Pathway 5			
Upper	411	12	29
Lower	419	12	28
Pathway 6			
Upper	419	12	32
Lower	428	13	31
Pathway 7			
Upper	539	16	33
Lower	578	18	32
Pathway 8			
Upper	401	12	41
Lower	408	12	40
Pathway 9			
Upper	495	15	40
Lower	526	16	38
Pathway 10			
Upper	422	12	40
Lower	436	13	39
Pathway 11			
Upper	473	14	35
Lower	504	15	34
Preferred Alternative			
Upper	419	12	34
Lower	410	12	35
Environmentally Preferred Alternative			
Upper	401	12	41
Lower	400	12	40



PA = Preferred Alternative

Figure 2.5. Health Effects Associated with Pathways

Short-term, acute effects have been identified for formaldehyde, particularly as an irritant of the eyes, skin, and respiratory tract. Within the range of 0.1 to 0.3 ppm, most people experience irritation to the eyes, nose, and throat. Between 10 and 20 ppm, symptoms are severe and breathing becomes difficult. Sensitive people, however, may experience symptoms at lower concentrations (less than 10 ppm).

Other pollutants associated with health effects were also considered, such as microorganisms and volatile organic chemicals, but valid risk factors do not yet exist for them, and our review indicated that the body of knowledge was insufficient to credibly determine their impacts on human health. While they have not been quantified, in general, the level of these effects change as ventilation rates change, as illustrated in Figure 2.4. They are reviewed in Chapter 4 and summarized here.

Particulates are composed of many compounds that, at elevated levels, can irritate eyes and mucous membranes. Dust is an irritant and can also carry gases or other substances into the lungs. Respiratory illnesses, especially chronic illnesses like bronchitis and emphysema, are linked to exposure to particulates (Diamond and Grimsrud 1984).

Particulates from cigarette smoking can irritate the eyes, nose, and throat, and cause coughing and headaches, especially for nonsmokers. But these effects are short-term and generally disappear when the offense is removed.

More information on the health effects related to smoking can be found in section 3.7.3 and Appendix K (Vol. II) to this Final EIS.

Because carbon monoxide combines with hemoglobin in the blood 220 to 250 times more readily than oxygen, it interferes with the delivery of oxygen throughout the body. At concentrations of 10-20 ppm, mild oxygen deficiencies can affect vision and brain function. Conditions such as headaches and irregular heartbeat can occur if concentrations reach 100 ppm. At higher concentrations, nausea, weakness, confusion, and possibly death can occur. Possible short-term health effects for various concentration levels of carbon monoxide are given in section 3.7.4.

Exposure to nitrogen oxides and nitrogen dioxide can irritate skin, eyes, and mucous membranes. Depending on the level and duration of exposure, respiratory effects range from slight irritation, to burning and pain in the chest, to violent coughing and shortness of breath (BPA 1984). Both compounds, like carbon monoxide, reduce the oxygen-carrying capacity of the blood. However, the physiological effects of nitrogen oxide at 3 ppm are similar to those of carbon monoxide at 10 to 15 ppm.

In healthy humans, respiratory functions generally are not affected at nitrogen dioxide levels of 1.5 ppm or below. But sensitive individuals can experience respiratory tract irritation at levels of 0.5 ppm or below. Children and persons with asthma, chronic bronchitis, and emphysema appear to be the most sensitive. In addition, persons with hay fever, or liver, hematological, or hormonal disorders may be affected.

Household chemicals contain such a wide variety of organic compounds that both short- and long-term health effects are difficult to assess. Each compound has different effects and, when products are combined, they may interact and produce still other health effects. Some compounds are irritants, while others are carcinogenic. Some affect the central nervous system, and some interfere with metabolic processes. Section 3.7.5 provides more information on this subject.

Moisture. Although water is not normally considered a pollutant, poor moisture control in buildings can lead to both health and structural effects. For health and comfort, relative humidity should be maintained at 30 to 50%. If the building is too dry, occupants can experience irritated mucous membranes, which can make the occupant more susceptible to infectious viruses. If the building is too humid, molds and mildew grow, which can exacerbate allergies. Since indoor humidity depends on outdoor conditions and moisture-generating activities (e.g., bathing), an MV system which operates in response to humidity provides the best control or mitigation of health effects from moisture problems. Continuous ventilation does not offer enough control and can lead to a house that is too dry. No mechanical ventilation can lead to more severe effects because indoor humidity levels can become too high with no efficient means of reducing those levels. Continuous air/vapor barriers are also thought to alleviate moisture problems by eliminating convective moisture transfer (Wilfert et al. 1986). Thus, Pathways 9 and 11 would provide the best control of health effects from moisture, followed by Pathways 3 and 5. Pathways 8 and 10, because of continuous ventilation, would be less effective, as would Pathways 2 and 4. Pathways 1 and 7 would result in the greatest health problems due to moisture.

Excess indoor moisture can damage the structural integrity of a house; thus, for structural considerations, lower moisture content is preferable. In most parts of the Pacific Northwest, the outdoor absolute humidity is less than the moisture indoors. Given this situation, exhaust MV systems are more suited to control humidity and thus the possibility of structural damage. Exhaust ventilation systems bring in the relatively dry outdoor air as it exhausts the moister indoor air, which keeps the wood structural members at a lower moisture content. Based on these criteria, Pathway 10, with a vapor/air barrier and an exhaust MV system, is ranked highest, followed by, in order, Pathways 11, 4, 5, 8, 2, 9, 3, 7, and 1.

Standard Package of IAQ Measures: Indoor air quality (IAQ) is enhanced in both the No Additional Action and Proposed Action Alternatives (all pathways) because of a standard package of minimum IAQ requirements. The adverse impacts that would result if those measures were not included are summarized below.

Consumer information on IAQ. If occupants are not aware of how to operate their energy-efficient homes, they might not turn on the MV system as frequently as they should. This would mean less fresh air in the house and thus more buildup of existing pollutants. Or, they would be unaware of the required maintenance activities, so over time the system would not operate as designed and not provide adequate ventilation. This would result in impacts described under all of the items listed below. The degree to which those effects would increase is not known because of the inability to predict consumer response to information. Also, without the IAQ information packets, occupants would not know about the radon package and the offer of monitoring or the need to implement radon mitigation measures. The effects would be the same as those described under the radon package.

Exhaust fans. If the house has no exhaust fans, there would be more moisture, with resulting health effects (e.g., molds, mildew, and allergic reaction). In addition, there would be a greater buildup of odors, smoke and carcinogenic organic substances from cooking, and volatile compounds from aerosol cleaners and other substances. Elevated levels of these pollutants could result in health effects ranging from respiratory irritation, headaches, and fatigue, to damage to the liver, kidney, and nervous system. Although studies have shown exhaust fans to be effective at removing pollutants from point sources (e.g.., stove top), insufficient data exist to estimate the positive effect on the health of occupants.

Venting for combustion appliances. If combustion appliances are not properly vented, there would be increases of some unknown amount in the levels of carbon monoxide, carbon dioxide, and nitrogen dioxide, and other respirable airborne particulates. Residents may experience mild oxygen deficiencies, which can affect vision and brain function; dizziness and nausea; and respiratory problems.

HUD standards for formaldehyde. Formaldehyde is a ubiquitous product in new homes (particle board and plywood). Without the product standard, residents will be more likely to experience short-term irritation of skin, eyes, mucous membranes, and respiratory track, and perhaps, in the long-term, nasal cancer.

Radon package. The radon package involves both monitoring and mitigation. Monitoring would have little direct effect on health because it only gives information. Mitigation does have a significant effect on radon reduction in an individual house (70%); but it is assumed that only about 2 1/2% of new households will actually take mitigative action. For that 2 1/2% of households, there may be a significant effect on health because that 2 1/2% will be from homes with the higher levels of radon concentrations and thus greater exposure. We can thus expect an increase in the incidence of lifetime lung cancers from radon exposure without this IAQ measure. The increase ranges from 10 to 40 lifetime cancers per 100,000 persons living in single-family and multifamily homes, and 1 to 12 additional cancers per 100,000 persons in manufactured homes.

2.4.4 Social and Economic Impacts

The primary socioeconomic effects are in the areas of fuel choice and energy savings. We assumed no energy savings in the Baseline. Under the No Additional Action Alternative, energy savings would range from 97 to 104 average megawatts for single-family homes, 21 to 28 average megawatts for multifamily homes, and about 37 to 39 average megawatts for manufactured homes. Regional expenditures under this Alternative are estimated to be 233 million dollars. The assumptions and methodology that yield these results are given in Appendixes E and G of Vol.II.

Because the program structure and incentives are the same for the Proposed Action and the No Additional Action Alternative, the number of new energy-efficient homes built during the program is also the same. However, the average ventilation rates for the pathways in the Proposed Action change depending on the infiltration and ventilation characteristics associated with the specific pathway. Therefore, the energy savings for the various pathways are basically proportional to the increase, or decrease, of the pathway's ventilation rate relative to the Baseline's (Figure 2.6). The analysis indicates that the continuous air barrier and the AAHX (with its heat recovery) are the two important factors for energy savings (see Tables 2.1 and 2.4). This is discussed more fully in section 4.3.

Regional expenditures range from 229 to 522 million dollars (Figure 2.7). These numbers reflect the cost of building the house; they do not include the program's administrative costs, which have not yet been determined. As expected, Pathway 1 is the least expensive as it includes no mechanical ventilation at all and only the standard insulation and caulking and other weatherization measures. Pathways 4 and 5 cost slightly more because they incorporate central exhaust systems; Pathway 6 costs an additional xxx million dollars to account for the blower door tests and the installation of ports in some percentage of the houses; Pathways 8 and 9 are the most expensive, accounting for both an air barrier and a central AAHX system.

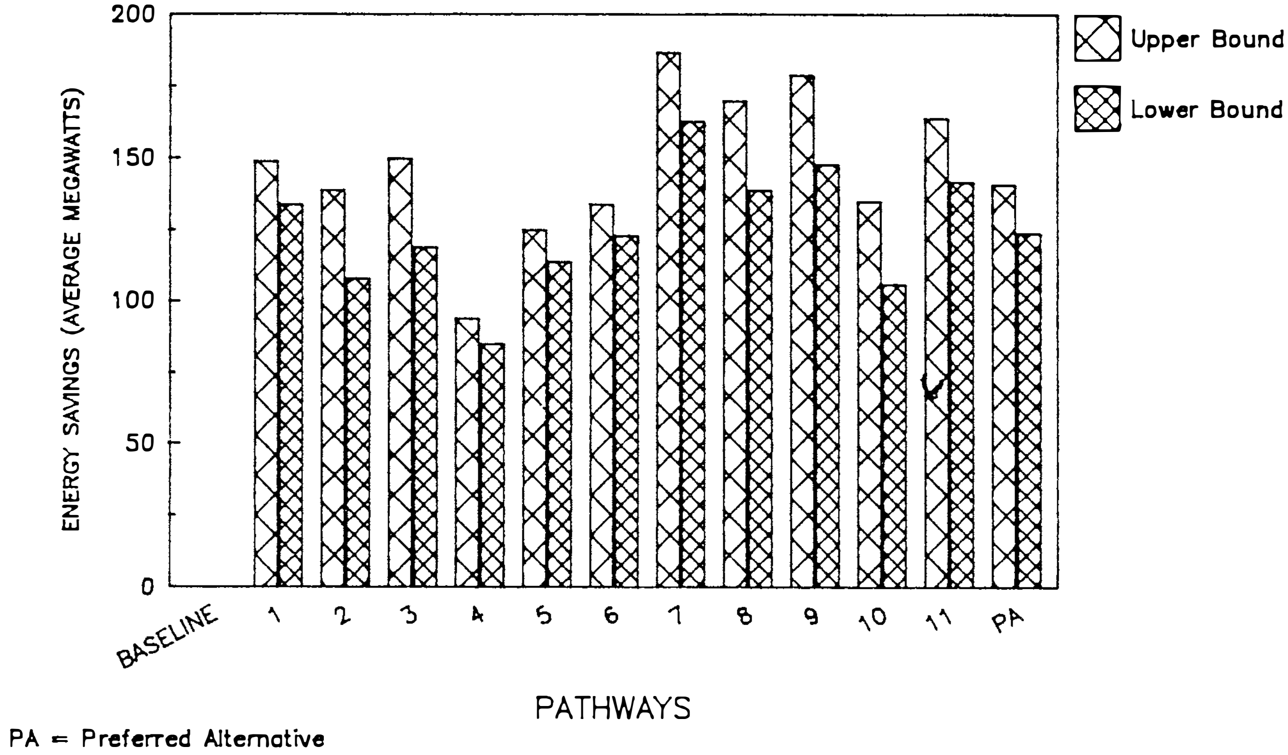


Figure 2.6. Energy Savings Associated with Pathways

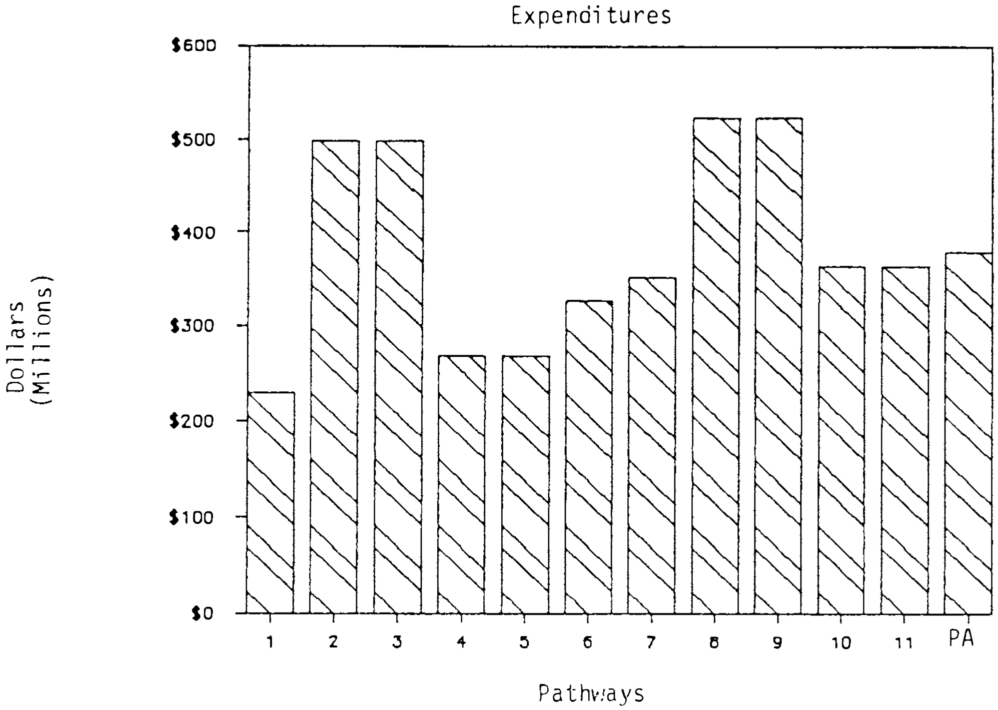


Figure 2.7. Expenditures Associated with Pathways

Fuel choice refers to the decision made by consumers to use electricity or alternative fuels for space heating. If, for example, gas-heated homes are not constructed to a required standard similar to MCS, they could have a first-cost advantage over new electrically heated homes built to such a standard. This may result in consumers favoring gas, oil, or wood over electricity.

The number of consumers choosing another fuel over electricity for space heating because of a standard for electrically-heated homes is given in BPA's 1986 medium growth forecast (BPA 1986a) of new homes. The addition of incentive payments dampens this effect. The number of new electrically-heated, single-family homes built from 1986 through 2006 is 603,337 for the Baseline and 436,630 for both the No Additional Action and Proposed Action Alternatives. The difference between these figures, 166,707 homes, is attributed to a choice of alternative fuels. This figure represents 28% of the number of homes forecast to be built under the Baseline. Under the same forecast, 2,898 multifamily households, or about 1% of the Baseline's 356,889 homes, would choose an alternative fuel for space heating. The forecast did not consider these effects for manufactured homes.

"Avoided impacts" refer to those environmental consequences avoided through the energy conservation effect of building MCS homes, because other, alternative generating resources are not required and thus not developed. BPA's 1986 resource strategy indicates that small hydropower would be the next resource to be developed if the conservation resource were not captured and if demand warranted it. Cogeneration, combustion turbines, and coal plants (only under high load obligations) would be the next generating facilities developed if demand exceeded what could be supplied by small hydropower. We calculated impacts avoided from the development of these additional resources for the No Additional Action Alternative and Pathways 4 and 7. The values are obtained by scaling from impacts estimated for typical plant sizes (500 MWe); thus some of the examples may give unrealistic impacts.

The No Additional Action saves 132 average megawatts (exclusive of manufactured homes). If that amount of energy had to generated by a small hydropower facility, 2.6 million acre-ft of water and 9050 acres of land would be required to develop a facility of that size (Table 2.7). The avoided impacts are directly proportional to the energy savings; thus, the alternative that achieves the highest energy savings will also result in highest avoided impacts from delaying construction of generating resources. For example, Pathway 4 saves less energy than the No Additional Action Alternative, so the impacts are less (Table 2.8); Pathway 7 saves more energy, so the impacts are greater (Table 2.9). Pathway 7 is the worst option for indoor air quality, but because it achieves the highest energy savings, it avoids more other environmental effects by reducing the need for generating resources; that is, to replace this amount of energy would require the largest alternative generation facility and thus result in the greatest impacts on the outdoor environment.

TABLE 2.7. Summary of Impacts of Avoided Power Generation - No Additional Action Alternative[a]

Environmental Impact	Small Hydropower	Municipal Solid Waste-Fired Cogeneration	Natural Gas-Fired Combustion Turbine	Coal-Fired Generator
Public mortality	Not reported in references	77[b]	0	.40
Public injuries and morbidity	Not reported in references	Not reported in references	.40	3.4
Solid waste, tons	0	(c)	Negligible	470,000
Air emissions, tons	Negligible	7,330	2,176	4,810
Water use	2.6 million acre-ft	17.0 million gal	504 acre-ft	607.0 million gal
Water consumption	0	263.0 million gal	Not reported	561 million gal
Land use, acres	9,050	137	25	229

(a) Assumed load reduction of 132 average megawatts.
(b) Mortality/morbidity combined.
(c) Burning solid waste as fuel results in a net reduction in solid waste requiring disposal.

2.5 THE PREFERRED ALTERNATIVE

Bonneville weighed a number of factors in its decision for the Preferred Alternative. These "decision factors" included such things as BPA's statutory mission under the Act to acquire the conservation resource, the administrative practicality of implementing the program, cost, energy savings, and consistency with BPA's environmental policy to protect the human environment. Of the many decision factors, health effects and flexibility were particularly important in developing the Preferred Alternative. For the first criterion we chose those pathways for which health effects were close enough to the Baseline to be within the range of uncertainty. Finally, within the tolerances allowed by the uncertainty surrounding the health effects and energy savings, we wished to allow maximum freedom and flexibility for builders and consumers. Once considered, these criteria determined which pathways were chosen and which were deleted from further consideration. Based on these criteria, BPA has chosen to include Pathways 3, 5, 6, 8 and 10 in its Preferred Alternative. These are described below in the order of the lowest to highest estimated cancer rate.

TABLE 2.8. Summary of Impacts of Avoided Power Generation for Pathway 4[a]

Environmental Impact	Small Hydropower	Municipal Solid Waste-Fired Cogeneration	Natural Gas-Fired Combustion Turbine	Coal-Fired Generator
Public mortality	Not reported in references	54[b]	0	.30
Public injuries and morbidity	Not reported in references	Not reported in references	.30	2.5
Solid waste, tons	0	(c)	Negligible	345,000
Air emissions, tons	Negligible	5,292	1,477	3,446
Water use	2.0 million acre-ft	12 million gal	357 acre-ft	431 million gal
Water consumption	0	197 million gal	Not reported in references	394 million gal
Land use, acres	6,523	96	17	160

(a) Assumed load reduction of 94 average megawatts.
(b) Mortality/morbidity combined.
(c) Burning solid waste as fuel results in a net reduction in solid waste requiring disposal.

The percentages of new homes assumed to be built to each selected pathway's specifications are reflected in the penetration rates (Table 2.10) used to estimate the effects of the Preferred Alternative. The distribution of percentages reflects the movement toward more advanced building designs over time. Other assumptions and the method for estimating the health effects, costs, and energy savings from this combination of pathways are described in Appendixes C, E, and G respectively.

Pathway 8 represents a departure from building practices of the past in that it includes the most up-to-date approach and technology that are widely available for both controlling infiltration and providing mechanical ventilation. It gives the occupant maximum control over the residence's environment. This pathway constitutes an option under MCS and SGC in 1987. Because of the continuously operated MV system, this pathway yields a ventilation rate that is equivalent to or exceeds the Baseline; thus its impact is to actually improve IAQ and health. It is one of the more expensive pathways because of the air barrier and heat recovery MV system, but also results in more energy savings because of those same features.

TABLE 2.9. Summary of Impacts of Avoided Power Generation for Pathway 7[a]

Environmental Impact	Small Hydropower	Municipal Solid Waste-Fired Cogeneration	Natural Gas-Fired Combustion Turbine	Coal-Fired Generator
Public mortality	Not reported in references	104[b]	0	.55
Public injuries and morbidity	Not reported in references	Not reported in references	.55	4.7
Solid waste, tons	0	(c)	Negligible	628,000
Air emissions, tons	Negligible	9,939	2,930	6,487
Water use	3.7 million acre-ft	24 million gal	670 acre-ft	806 million gal
Water consumption	0	366 million gal	Not reported in references	764 million gal
Land use, acres	12,555	188	35	314

(a) Assumed load reduction of 187 average megawatts.
(b) Mortality/morbidity combined.
(c) Burning solid waste as fuel results in a net reduction in solid waste requiring disposal.

TABLE 2.10. Distribution For Preferred Alternative

Pathway	Percent Penetration 1987 - 1992	1993 - 2002	2003 - 2006
3	30	10	5
5	45	50	20
6	5	10	5
8	20	25	40
10	0	5	30

Pathway 5 represents the Council`s 1987 MCS and the SGC base home. Its central exhaust MV system is also operated intermittently, yet provides enough ventilation that its total rate is within the uncertainty range of the Baseline. The use of vents (or ports) is an inexpensive means of providing more controlled ventilation and a balance between air inflow and outflow. These intake vents are small and strategically placed to permit better air mixing with the warm rising air (thus avoiding drafts) and better distribution of the fresh air throughout the dwelling. However, this pathway does not achieve the energy savings that would be derived from the air barrier and AAHX.

Pathway 3's energy savings reflect the benefits of heat recovery through the AAHX. It also represents a realistic option because the intermittent operation of the MV system more closely approximates how occupants generally tend to run the system. Intermittent operation of the system also uses less energy than continuous operation and thus contributes to energy savings. The resulting ventilation rates are close enough to those of 1983 practice that it should not increase adverse health effects relative to the Baseline.

Pathway 10 is included as an option to be implemented in the future when the technology for continuous operation of an exhaust fan-controlled system is more widely accepted in this country, as it now is in Europe. The continuous operation will give a ventilation rate within the uncertainty range of the Baseline, even with its very tight construction; the advanced construction adds more to the cost but will allow for some energy savings (800-1130 more kwh per house than its counterpart in Pathway 4) despite the lack of heat recovery in its MV system.

Pathway 6 has an intermittently operated exhaust system, but without the makeup air ports, unless the required blower door test indicates a need for them. A scenario in which no houses are retrofit with ports yields the highest cancer rate possible for this pathway; even though it is not the most likely scenario, our health effects analysis uses this assumption in order to determine the maximum effect of the pathway. The result is slightly more cancers, slightly more energy savings, and a higher cost than Pathway 5. The pathway offers more flexibility to builders but less control over ventilation distribution to the homeowner.

The other pathways were excluded from the Preferred Alternative either because they had ventilation rates that were too low in comparison to prevailing building practice (Pathways 1, 7, 9, and 11) and would thus result in unacceptable health effects, or because too much energy is lost to higher ventilation rates (Pathways 2 and 4).

2.6 THE ENVIRONMENTALLY PREFERRED ALTERNATIVE

In Pathway 8, the Environmentally Preferred Alternative, lifetime cancer rates from radon exposure actually decrease relative to the Baseline. This is due to primarily the programmatic requirement for mechanical ventilation in tight homes. The additional mechanical ventilation required in tight homes results, on average, in a higher total effective ventilation rate than is achieved in baseline homes, and thus lower pollutant concentrations and reduced cancer rates. Also, because of the energy savings achieved through this pathway, it avoids other environmental effects that would be incurred by a generating facility developed to provide the energy acquired through this conservation resource.

AFFECTED ENVIRONMENT

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The New Energy-Efficient Homes Programs are designed to encourage the addition of energy-efficient building features in new homes. To this end, the programs must necessarily operate in the context surrounding new home construction. That context comprises the shelter industry, the housing market, building practices, housing forecasts, the affected population, and the quality of air inside homes, which are the subject of this chapter.

3.1 SHELTER INDUSTRY

The shelter industry consists of a diverse group that comprises the building trades, manufacturing sectors, and financial and marketing sectors. Industry groups include design professionals, builders, contractors, and developers; manufacturers of construction materials and systems; and lenders, appraisers and realtors. The most striking characteristic of this industry is its very diversity, necessitated by the many actors who have a stake in building new homes.

Design professionals and architects interact with building clients, financiers, builders, engineers, realtors, and material manufacturers to coordinate the production of buildings, from the selection of the site through occupancy of the new house. Given state and local energy codes and voluntary standards such as the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90, designers, particularly architects and mechanical and electrical engineers, require a fairly good understanding of energy use in buildings and its relationship to building design.

The construction professions--builders, contractors, and developers--are responsible for most residential construction, although they also become involved with the design and construction of many other building types. They generally use building plans and technical information supplied by architects, trade magazines, home builder associations, and materials manufacturers. This industry tends to be locally oriented, sensitive to both market and cost, and subject to seasonal variations in building construction. Numerous building and construction organizations (e.g., National Association of Home Builders, Associated General Contractors) provide newsletters, journals, meetings, and workshops to acquaint the construction trades with new standards, materials, and techniques. Given the diversity of building projects, the industry's mode of operation, and the various specializations within the group, it is difficult to make any other generalizations regarding this industry and what its response is likely to be to any program for energy-efficient new homes (DOE 1980).

Implementation of energy-efficient standards may affect some manufacturers of components and building materials. For example, new construction sales may expand in the insulation industry (for R-38 and above). Manufacturers of 2-in. x 6-in. boards, double-glazed windows with thermal breaks, and AAHXs may also be affected. Since some radon mitigation techniques require the use of PVC pipe and various fans, suppliers of plumbing and electrical appliance may also be affected.

The home building industry--the firms actually producing finished housing--is complex and unstable, with a great number of small firms and high rates of entry and exit. It is also characterized by "fragmentation of the production process," operating through ad hoc arrangements among a variety of subcontractors. Of the eight major home building operations (electrical work; framing; grading the lot; heating, ventilation, and air conditioning; insulation; landscaping; plumbing; and marketing and sales), only framing and marketing and sales are usually done by a home building firm's own employees, relying on subcontractors for the other work. Thus, subcontractors make many of the decisions and control many of the procedures important to the construction of energy-efficient houses (see Economic and Social Effects of the Model Conservation Standards, Appendix D in Vol. II of the DEIS).

The nature of the industry, in which a single construction project involves numerous, relatively autonomous actors, has much to do with the place of innovation in the industry. In general, the industry reacts slowly to any change: partially because of its fragmentation; partially because of its use of inexpensive labor, which can be effective performing the same task over and over, but ineffective doing things differently; and partially because of the risk taken by the builder for doing anything other than in the normally accepted way. Construction of energy-efficient, and radon-resistant houses, requires development or use of new materials (e.g., vapor barriers), modification of procedures and techniques, and adjustments in the interactions among participants in the system (e.g., training contractors and contractors teaching each of their subcontractors). For these reasons, large-scale builders have proved to be more resistant to the modifications necessary to build energy-efficient homes. Contractors who build a small number of homes per year are more likely to take the time for the training necessary to learn new theories and construction practices, be onsite more of the time, and establish a network of subcontractors who have learned to build to energy-efficient standards. These are the builders and contractors most likely to welcome innovation and be advocates of the program.

3.2 HOUSING CHARACTERISTICS

To determine the environmental effects of BPA's New Energy-Efficient Homes Program, it is necessary to compare the characteristics of energy-efficient homes with those of houses built using baseline practices. The differences in design, thermal performance, and ventilation rate form the basis for calculating potential energy savings, health effects, costs, and other impacts of the alternatives. These differences are discussed here.

3.2.1 Design Characteristics

To compare and analyze energy savings and costs, we used six building prototypes: three single-family buildings, one multifamily building, and two manufactured houses. The characteristics and dimensions of these six prototypes are detailed in New Homes Conservation Resource, Appendix A in Vol. II of the DEIS. The definitions of the structures are as follows:

- single-family dwelling - a structure consisting of four or fewer residential units, designed to be permanently located at one site; may be site-built, modular, or prefabricated

- multifamily dwelling - a structure consisting of more than four residential units, with a common wall and foundation, designed to be permanently located at one site

- manufactured home - sometimes referred to as a mobile home; transportable in one or more sections; built on a permanent chassis, and designed to be used as a dwelling; not required to meet local code requirements but must meet standards promulgated by the U.S. Department of Housing and Urban Development (HUD).

3.2.2 Thermal Efficiency

Building practices also differ for various climate zones as builders have adjusted to different climatic conditions. As part of the specifications and standards established for energy-efficient homes, BPA and the Council have established climate zones throughout the Northwest (Figure 3.1) based on the number of heating degree days (HDD), as follows:

- Zone 1 - Fewer than 6,000 HDD, found in the mild maritime climate west of the Cascade Mountains and other temperate areas

- Zone 2 - 6,000 to 8,000 HDD, found in the harsher, eastern parts of the region

- Zone 3 - More than 8,000 HDD, found in western Montana and higher elevations throughout the region.

To define the changes being promoted by the MCS, we first examined the Baseline from which those changes are being made. Baseline construction practices have resulted in the thermal characteristics shown in Table 3.1. The numbers in Table 3.1 are based on surveys of building practices conducted for BPA, surveys of state energy agencies, and existing code requirements. The newly revised Washington and Oregon codes are reflected in Table 3.2.

Energy-efficient homes can be constructed in many different shapes and can incorporate many different features. The specific shape and features a builder chooses will depend on such factors as cost, climate, consumer preference, and local building codes. Energy-efficient homes that meet BPA's standards have a target energy consumption level. As long as the final design meets the target, which will vary from house to house, builders may select from among a variety of energy-saving features. For comparison with the thermal characteristics shown in Table 3.1 for a 1983 practice home, the characteristics shown in Table 3.3 are those that meet the MCS targets for each of the climate zones. The thermal characteristics listed in all three tables are, except for windows, expressed in R-values, which refer to a material's ability to resist heat flow. The higher its R-value, the more effective a material functions as an insulator.

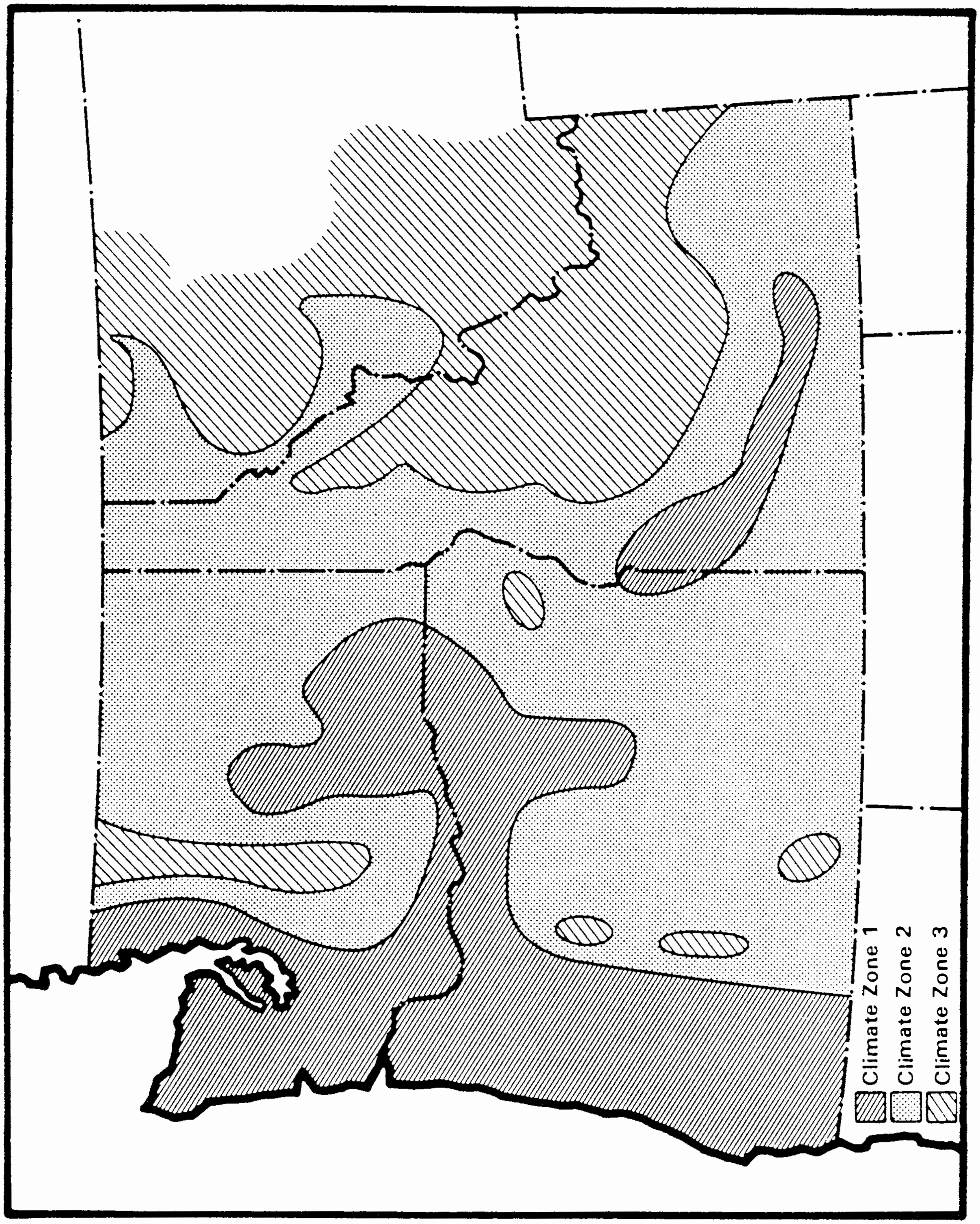


FIGURE 3.1. Climate Zone Map

TABLE 3.1. Thermal Characteristics of New Homes Built to 1983 Practice

Building Type	Component	Climate Zone 1	Climate Zone 2	Climate Zone 3
Single-family	Ceiling/roof	R-30	R-30	R-38
	Walls	R-11	R-11	R-19
	Underfloor	R-11/19	R-19	R-19
	Glazing	Double-glazed (U-.90)	Double-glazed (U-.90)	Double-glazed (U-.65)
Multifamily	Ceiling/roof	R-30	R-30	R-30
	Walls	R-11	R-11	R-11
	Underfloor	R-11/19	R-19	R-19
	Glazing	Double-glazed (U-.90)	Double-glazed (U-.90)	Double-glazed (U-.65)
Manufactured housing	Ceiling/roof	R-9.1	R-9.1	R-9.1
	Walls	R-15.8	R-15.8	R-15.8
	Underfloor	R-14.4	R-14.4	R-14.4
	Glazing	Double-glazed (U-.50)	Double-glazed (U-.50)	Double-glazed (U-.50)

Source: NWPPC 1986; BPA 1987b.

Another term describing insulating qualities is U-value, which refers to a material's ability to conduct heat. Mathematically, U-values are inversely proportional to R-values. If a material has a high resistance (R-value) to heat flow, its conductivity (U-value) is low; if its conductivity is high, its resistance is low. U-values are used to calculate the overall thermal efficiency of a building shell. These calculations take into account the area and U-value for each component of a building such as windows, doors, walls, ceilings, and floors and result in an overall value for the entire area of a structure represented by UA. The lower the UA for a building, the more thermally efficient it is. The UA values for energy-efficient and baseline homes are shown in Tables 3.4 and 3.5 for both upper and lower bounds of ventilation rates.

3.2.3 Air Exchange Rates

Air exchange is another important determinant of a home's energy efficiency, and can be either controlled or uncontrolled. Air leakage is the uncontrolled passage of air, or infiltration, through the shell of a home. Indoor air is replaced through either passive or active ventilation (also termed natural or mechanical). Prevailing building practices usually rely on natural ventilation for the exchange of indoor and outdoor air. Natural ventilation includes operable windows and doors and infiltration. Mechanical ventilation is characterized by mechanical devices designed to move air throughout a structure or in a limited area with localized concentrations of pollutants.

TABLE 3.2. Thermal Characteristics of New Homes Built to Washington and Oregon State Codes

State	Building Type	Component	Climate Zone 1	Climate Zone 2
Washington	Single-family	Ceiling/Roof	R-38	R-38
		Walls	R-19	R-19
		Underfloor	R-19	R-25
		Glazing	(U-.60)	(U-.60)
	Multifamily	Ceiling/Roof	R-38	R-38
		Walls	R-19	R-19
		Underfloor	R-19	R-25
		Glazing	(U-.60)	(U-.60)
Oregon	Single-family	Ceiling/Roof	R-38	R-38
		Walls	R-19	R-19
		Underfloor	R-19	R-19
		Glazing	(U-.75)	(U-.75)
	Multifamily	Ceiling/Roof	R-38	R-38
		Walls	R-19	R-19
		Underfloor	R-19	R-19
		Glazing	(U-.75)	(U-.75)

Source: Oregon 1986; Washington 1986.

Ventilation rates are usually given as average air changes per hour (ACH), which refers to the rate at which air inside the home is replaced by outside air. The more tightly constructed a residence is, the lower its air change rate will be, unless an MV system is used.

Natural Ventilation

Air leakage and occupant behavior contribute to natural ventilation. Sites of air leakage in homes built using current construction practices are indicated in Figure 3.2. The air infiltration in buildings is caused by two primary, interdependent factors: the local wind field and the indoor-outdoor temperature difference, which cause a pressure differential to be exerted on the building's envelope. In addition, the use of combustion appliances contributes to these pressure differences. As these forces change, infiltration rates change accordingly. These three driving forces are illustrated in Figure 3.3 and explained below.

- Wind pushes outdoor air through leaks on the windward side of buildings, as illustrated in Figure 3.3a. And wind passing around a building creates lower pressure on the leeward side, which pulls indoor air out.

TABLE 3.3. Thermal Characteristics of Homes Built To The MCS

Component	Climate Zone 1	Climate Zone 2	Climate Zone 3
Single-family			
Ceiling			
Attic	R-38(U-0.032)	R-38(U-0.032)	R-49(U-0.021)
Vaults	R-38(U-0.028)	R-38(U-0.028)	R-38(U-0.028)
Walls			
Above grade	R-19(U-0.057)	R-24(U-0.043)	R-26(U-0.039)
Below grade (interior)	R-19	R-19	R-19
Underfloors			
Crawl spaces and perimeters	R-30(U-0.03)	R-30(U-0.03)	R-30(U-0.03)
Slab floor perimeters	R-10(U-0.455)	R-10(U-0.455)	R-10(U-0.455)
Glazing	R-2.5(U-0.40)	R-2.5(U-0.40)	R-2.5(U-0.40)
Maximum glazed area (% floor area)	15%	15%	15%
Exterior doors	R-5(U-0.19)	R-5(U-0.19)	R-5(U-0.19)
Multifamily			
Ceiling	R-38(U-0.032)	R-38(U-0.032)	R-49(U-0.032)
Walls	R-19(U-0.057)	R-24(U-0.043)	R-26(U-0.039)
Below-grade wall	R-19(U-0.75)	R-19(U-0.75)	R-19(U-0.75)
Underfloors			
Floor over unconditioned space	R-30(U-0.03)	R-30(U-0.03)	R-30(U-0.03)
Slab floor perimeters	R-10(U-0.455)	R-10(U-0.455)	R-10(U-0.455)
Glazing	R-2.5(U-0.40)	R-2.5(U-0.40)	R-2.5(U-0.40)
Maximum glazed area (% floor area)	15%	15%	15%
Exterior doors	R-5(U-0.19)	R-5(U-0.19)	R-5(U-0.19)

Source: BPA 1987c.

° The stack effect (or chimney effect) is the tendency of warm interior air to rise and escape through leaks near the ceiling, as illustrated in Figure 3.3b. As this happens, outdoor air enters through openings near the floor, and soil gas containing radon can enter through cracks and holes in foundations and slabs. The temperature difference between indoors and outdoors determines the rate of leakage due to the stack effect. The stack effect is more pronounced in taller buildings, being more prominent in multistory homes than in single-story homes.

TABLE 3.4. Comparison of UA Values in 1983 Practice and Energy-Efficient Prototypes (Upper Bound)

	Climate Zone 1				Climate Zone 2				Climate Zone 3	
	1983 Practice	OR Code	WA Code	Energy-Efficient	1983 Practice	WA/OR Code	ID Code	Energy-Efficient	1983 Practice	Energy-Efficient
Prototype	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA
Single-family										
1344 ft^2	481	426	382	308	464	389	382	292	382	273
1848 ft^2	593	521	468	378	576	463	468	350	468	336
2352 ft^2	762	687	649	449	754	530	555	435	545	416
Multifamily	2358	2053	1836	1602	2308	1855	1836	1492	1836	1429
Manufactured housing										
Single-section	377			226	377			223	377	216
Multi-section	472			277	472			273	472	265

TABLE 3.5. Comparison of UA Values in 1983 Practice and Energy-Efficient Prototypes (Lower Bound)

	Climate Zone 1				Climate Zone 2				Climate Zone 3	
	Current Practice	OR Code	WA Code	Energy-Efficient	Current Practice	WA/OR Code	ID Code	Energy-Efficient	Current Practice	Energy-Efficient
Prototype	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA
Single-family										
1344 ft^2	460	404	361	292	442	367	361	277	361	257
1848 ft^2	563	492	439	356	547	434	439	329	439	315
2352 ft^2	724	650	612	422	717	493	518	408	508	389
Multifamily	2176	1871	1654	1486	2127	1673	1654	1376	1654	1313
Manufactured housing										
Single-section	375			222	375			219	375	212
Multi-section	470			271	470			268	470	259

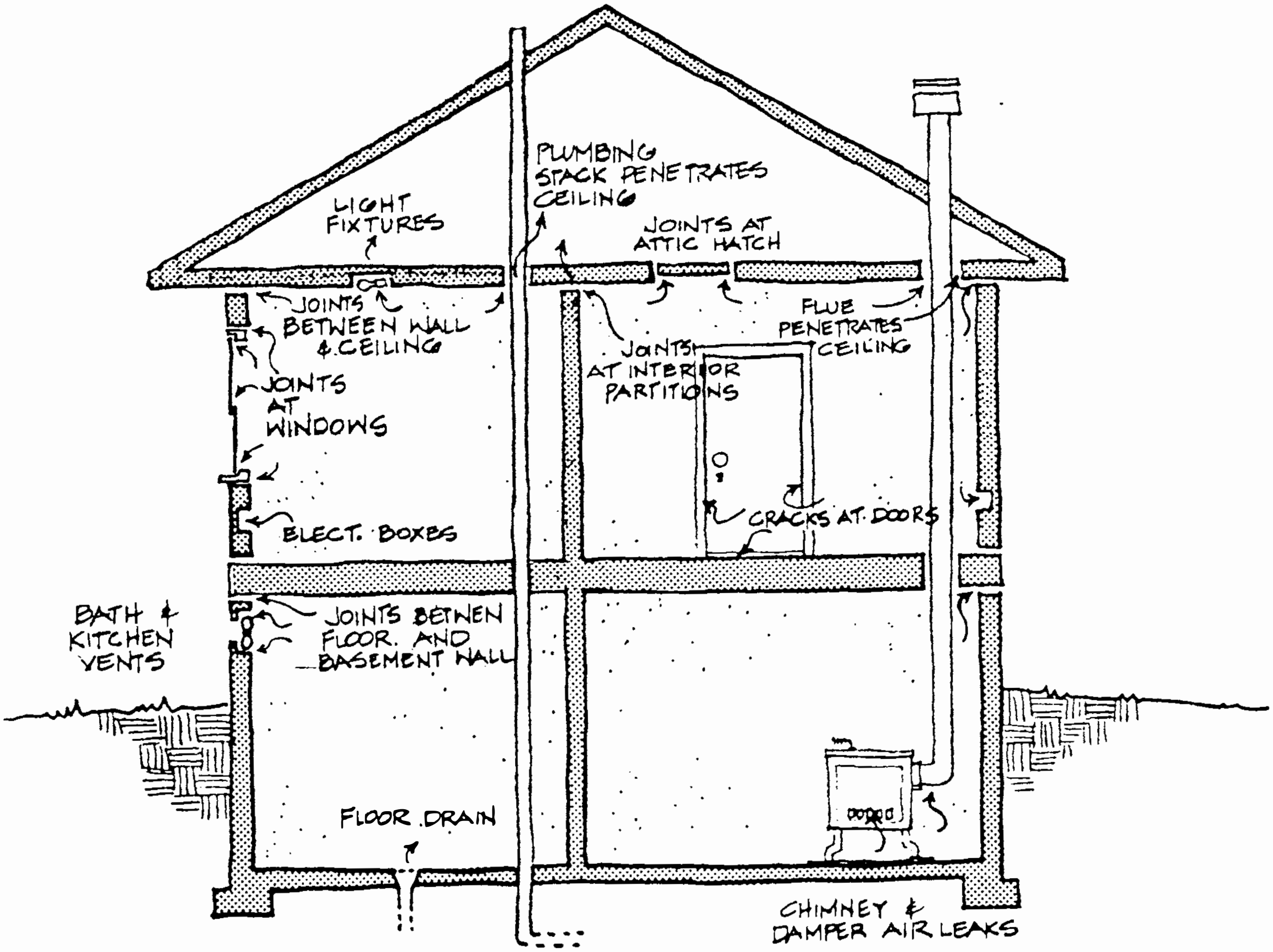
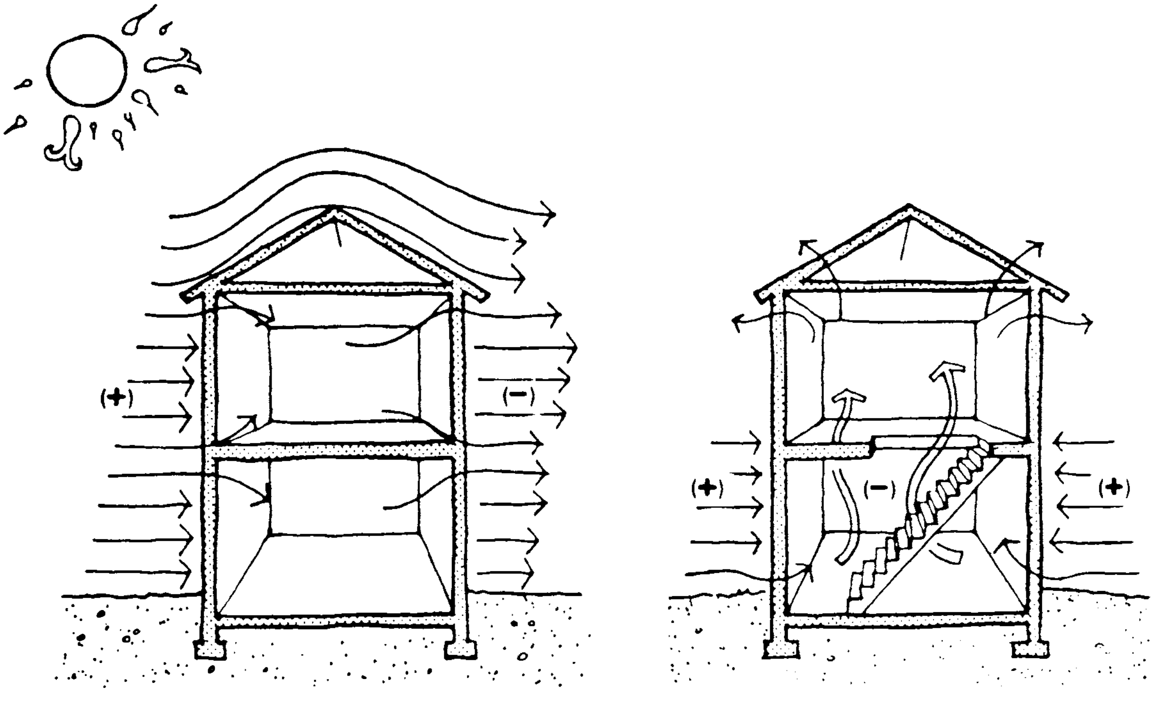


FIGURE 3.2. Air Leakage in Conventional Houses (BPA 1985)

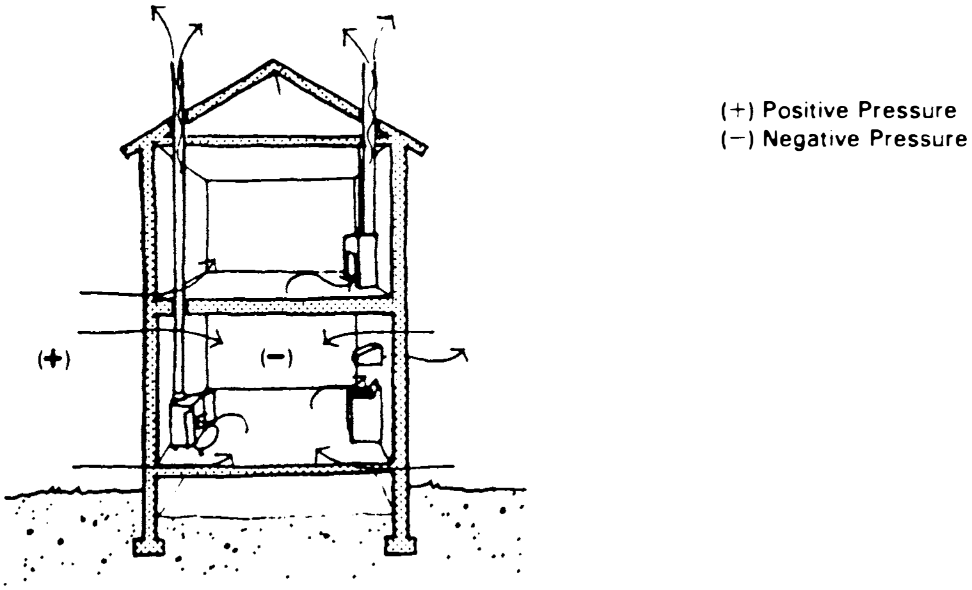
° Combustion appliances such as wood stoves require large amounts of air to support the burning of fuel and to create a proper draft in the flue. As flue gases escape, air is drawn through openings in the building shell (Zerba and Parker 1985; Diamond and Grimsrud 1984). An air-tight woodstove draws about 20 cubic feet of air per minute (CFM), and an open fireplace may draw as much as 400 CFM. The effects are shown in Figure 3.3c. Mechanical ventilation devices such as exhaust fans that force air out of a building but do not use fans to pull in an equal amount of air also cause a pressure difference between a house's interior and exterior.

Blocking the air pathways around windows and doors and through joints and cracks can prevent 25 to 40% of a total building's heat loss (Diamond and Grimsrud 1984). In energy-efficient homes, infiltration is controlled by blocking air routes with caulking, weatherstripping, and other sealants or by installing continuous air barriers. The barriers consist of materials that block air movement, carefully installed to be continuous around the entire shell of the home. Special care is taken at joints in the material, at penetrations for wiring and plumbing, and at intersections between walls, floors, and ceilings to seal leaks and maintain continuity. Materials used in making air barriers include 6-mil polyethylene plastic sheets, rigid insulation board, and drywall.



A. Wind

B. Stack Effect



C. Combustion Appliances and Exhaust Fans

FIGURE 3.3. Driving Forces of Infiltration (BPA 1985)

The activities of the building's occupants also influence natural ventilation. For example, when occupants close up a home in the winter, the air change rate can be lower than during the summer when doors and windows remain open. In sum, wind speed, temperature, time of year, and occupant living patterns combine to affect how much air comes from passive ventilation. The range of air change rates from passive ventilation is shown in Figures 3.4 and 3.5. In these examples of homes in Bend, Oregon, and Vancouver, Washington, the ventilation rate varied from less than 0.2 ACH to over 0.7 ACH in the Vancouver home and from about 0.2 ACH to over 1.0 ACH in the Bend home (Zerba and Parker 1985). The average air exchange rates were 0.27 and 0.22 ACH, respectively.

Mechanical Ventilation

Mechanical ventilation refers to the air intentionally supplied by mechanical devices such as fans, ducts and motors that maintain a steady level of ventilation. The equipment can be sized to deliver any desired level of ventilation.

Equipment designed to circulate air throughout an entire structure is called "whole-house ventilation." The fans that push the air are often centrally located, and air is moved and delivered via a system of ducts, just as with central forced-air heating systems. These systems may be coupled with a device such as an AAHX or a heat pump to capture some of the heat lost in outgoing air.

Mechanical ventilation can also be used to remove air from limited areas such as kitchens, bathrooms, or home workshops with high levels of pollutants or moisture. In these applications the systems are often called "spot ventilation."

Mechanical ventilation systems can be either balanced or unbalanced. Balanced systems use fans, or controlled openings, to replace air removed from indoors with air from the outdoors. Unbalanced systems either supply or exhaust air, but do not actively do both. These systems are called unbalanced because air is mechanically moved predominantly in only one direction, either into or out of the house, resulting in a pressure difference between inside the home and outside. For example, if an exhaust fan is used, indoor air is pulled to the outdoors, resulting in less (negative) pressure inside the home than outside. The pressure difference forces outside air to enter the home through cracks and joints or through vents specifically for that purpose. Pollutants originating outdoors, such as radon, may be drawn into a home along with outdoor air under these circumstances.

Measured Ventilation Rates

As described in Chapter 2, BPA used both fan pressurization tests and PFT tests to measure ventilation rates in the RSDP homes. Fan pressurization, or "blower door", tests measure the effective leakage areas (ELA) of structures by using a fan to pressurize or depressurize a structure to a given level. The pressure difference between indoors and outdoors is then

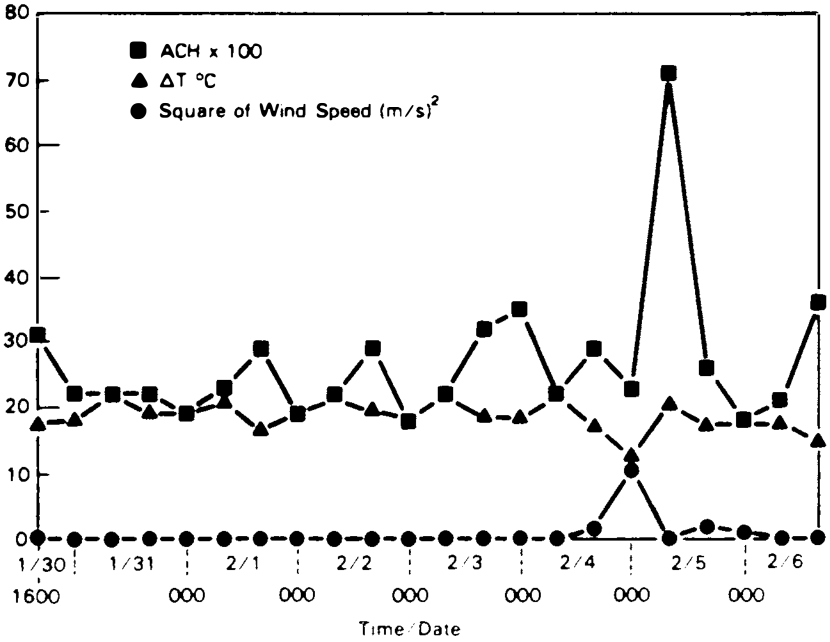


FIGURE 3.4. Measured Air Exchange Rate, Wind Speed, and Inside-Outside Temperature in a Vancouver Residence (1/30/82-2/6/82) (Zerba and Parker 1985, Figure 1)

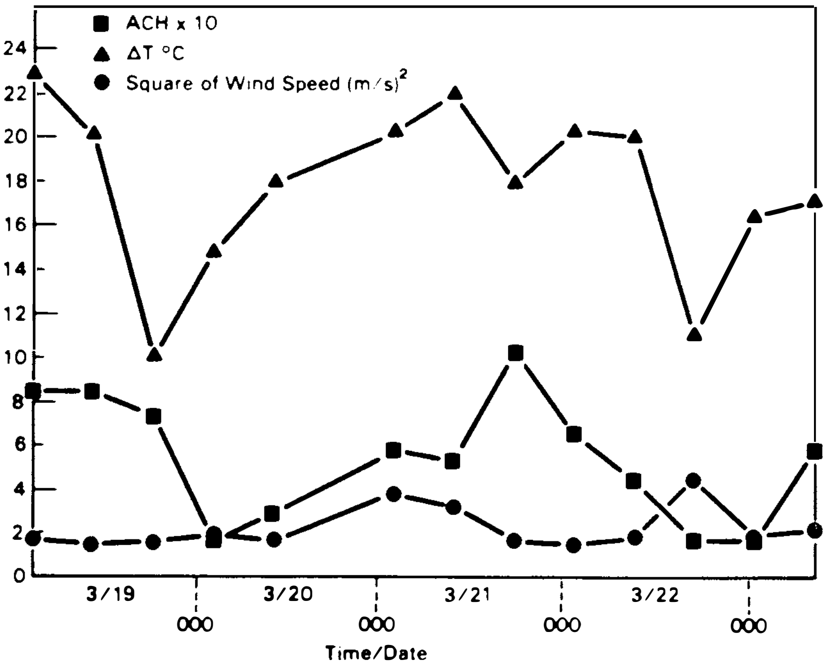


FIGURE 3.5. Measured Air Exchange Rate, Wind Speed, and Inside-Outside Temperature in a Bend Residence (3/19/82-3/23/82) (Zerba and Parker 1985, Figure 5)

measured and used to estimate air leakage. This method measures only the flow rates given a specific pressure difference.

Fan pressurization tests in a sample of typical new homes built under the RSDP found a median air leakage rate of about 0.51 ACH, with a range of from less than 0.1 to more than 1.0. ACH. Energy-efficient homes, comparable in style and location, were found to have a median of about 0.20 ACH, with a range of from 0.02 to 0.9 ACH (BPA 1986d; Harris 1986). The measurements of air leakage in energy-efficient homes do not include contributions from mechanical ventilation.

Perfluorocarbon tracer (PFT) gas tests measure air exchange rates in a building by releasing a known quantity of a tracer gas throughout the ventilated space and monitoring changes in gas concentration over time. This method accounts for contributions to ventilation from air leakage, occupant behavior, and mechanical devices.

Results from the PFT tests showed ventilation rates of about 0.28 ACH in homes built to 1983 practice, and about 0.26 ACH in energy-efficient homes. These are integrated rates taken over a 3-month heating season period and represent an "effective" ventilation rate. The PFT results and fan pressurization results are shown in Table 3.6.

Under BPA's Energy-Efficient Homes Programs described in the No Additional Action Alternative, tight energy-efficient homes are required to supplement infiltration with mechanical ventilation. These systems must provide a balanced flow of outdoor and indoor air, and are designed to bring ventilation rates up to levels found in 1983 practice. These systems are described in Indoor Air Quality Mitigation Technologies, Appendix C, Vol. II to the DEIS, and updated in Appendix M to this Final EIS.

Based on the UA data listed in Tables 3.4 and 3.5, differences in air leakage between 1983 practice and energy-efficient homes, and other characteristics such as internal heat gains, we calculated the energy savings presented in Table 3.7 for prototypical energy-efficient homes. The assumptions and sensitivity analyses used in the calculation are provided in the DEIS, Vol. II, Appendix A.

TABLE 3.6. Median Measured Ventilation Rates in New Northwest Single-Family Houses

House Type	Fan Pressurization Test Results, ACH	PFT Test Results, ACH
1983 practice	0.51	0.28
Energy-efficient with air barrier	0.20	0.26

Source: Harris 1986.

TABLE 3.7. Annual Energy Savings by Climate Zone for Prototypical Energy-Efficient Homes (Pathway 5)

Prototype	Savings per Unit, kilowatt-hours (kWh)					
	Climate Zone 1		Climate Zone 2		Climate Zone 3	
Single-family	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
1,344 ft^2	3684	3523	4683	4452	4903	4636
1,848 ft^2	4689	4460	5894	5575	6040	5670
2,352 ft^2	7407	7378	6654	6248	5826	5358
Multifamily (per unit)	1100	860	1615	1304	1461	1141
Manufactured housing						
Single-section 924 ft^2	3397	3459	5481	5578	6732	6846
Multisection 1344 ft^2	4753	4850	7350	7495	8985	9156

3.3 HOUSING COSTS

The incremental construction cost of adding energy-efficient features to a new 1848 sq. ft. home ranges from $1567 in climate zone 1 to $2727 in climate zone 3, where more energy-efficient measures are needed to accommodate the colder climate. The costs for all the prototypes analyzed are shown in Table 3.8. These figures translate into an additional $.56 to $1.48 per square foot, and cover the costs of the additional insulation, window treatments, and mechanical ventilation required to meet minimum MCS levels. They do not include the costs of various mitigation measures such as are found in the radon package. Those costs are given in Appendix E, which treats the costs of the different alternatives.

3.4 FORECASTS OF NEW HOME CONSTRUCTION

Bonneville's 1986 forecasts of new home construction in the region provide the basis for predicting the number of new homes that will be built during the 1986-2006 time frame. The forecasts were made by Bonneville's Economic Forecasting Section of the Division of Power Forecasting, using a regional/employment model (BPA 1986a). These forecasts are summarized in Tables 3.9 through 3.11. In Table 3.9, the number and types of new electrically heated homes forecast to be built under the Baseline are shown. Forecasts of construction are shown in Tables 3.10 and 3.11 for the No Additional Action Alternative. The total number of electrically heated homes varies from

TABLE 3.8. Incremental Construction Costs of Prototypical New Energy-Efficient Homes by Climate Zone (Pathway 5)

Prototype	Incremental Cost of Construction, $ Climate Zone 1	Climate Zone 2	Climate Zone 3
Single-family			
1,344 ft^2	1,319	1,643	2,207
1,848 ft^2	1,567	2,175	2,727
2,352 ft^2	1,418	1,280	1,319
Multifamily (per unit)	641	788	925
Manufactured housing[a]			
Single-section 924 ft^2	1,153	1,153	1,153
Multisection 1,344 ft^2	1,898	1,898	1,898

(a) Manufactured housing costs are net disaggregated by climate zone in BPA 1987b.

Source: BPA 1986e.

the Baseline to the No Additional Action Alternative because of fuel choice decisions; i.e., the forecasts assumed that some percentage of new home buyers would choose to heat their homes with a fuel other than electricity, regardless of the incentives offered from 1986 through 1988.

Changes are made in the forecasts from year to year to reflect changes in the regional economy. The most important change between the 1985 and 1986 forecasts has been the adoption of new building codes by the Oregon and Washington legislatures. The result of this change is that fewer consumers are forecasted to choose electric space heat for their new homes.

Other changes include a substantial reduction in fossil fuel prices and projection of slower population growth. All told, the cumulative total for new single-family electric construction is about 12% lower for the 1986 forecast than for the 1985 forecast (Otstot 1986).

3.5 POPULATION

The number of people likely to be affected by the New Energy-Efficient Homes Programs is based on the data in Tables 3.9 through 3.11 multiplied by the number of people per home per year shown in Table 3.12. The affected regional population is displayed in Table 3.13.

TABLE 3.9. New Electrically Heated Homes Construction Forecast for the Baseline

	Regional Total			Climate Zone 1			Climate Zone 2			Climate Zone 3		
Year	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured
1986	22,845	13,629	9,178	14,506	10,208	5,663	7,333	3,107	3,084	1,005	300	422
1987	27,575	16,655	10,563	17,510	12,475	6,517	8,851	3,797	3,549	1,213	366	486
1988	26,310	15,844	10,210	16,707	11,867	6,300	8,446	3,612	3,431	1,158	349	470
1989	32,522	20,202	11,893	20,651	15,131	7,338	10,439	4,606	3,996	1,431	444	547
1990	29,053	17,147	11,096	18,449	12,843	6,846	9,326	3,909	3,728	1,278	377	510
1991	29,999	17,705	11,420	19,049	13,261	7,046	9,630	4,037	3,837	1,320	390	525
1992	27,424	15,793	10,894	17,414	11,829	6,722	8,803	3,601	3,661	1,207	347	501
1993	27,723	15,924	11,078	17,604	11,927	6,835	8,899	3,631	3,722	1,220	350	510
1994	29,158	16,835	11,541	18,515	12,609	7,121	9,360	3,838	3,878	1,283	370	531
1995	28,215	16,191	11,430	17,916	12,127	7,052	9,057	3,692	3,841	1,241	356	526
1996	28,477	16,502	11,586	18,083	12,360	7,149	9,141	3,762	3,893	1,253	363	533
1997	28,463	16,487	11,678	18,074	12,349	7,205	9,137	3,759	3,924	1,252	363	537
1998	29,022	16,941	11,911	18,429	12,689	7,349	9,316	3,863	4,002	1,277	373	548
1999	28,364	16,525	11,861	18,011	12,377	7,318	9,105	3,768	3,985	1,248	364	546
2000	28,663	16,838	12,117	18,201	12,611	7,476	9,201	3,839	4,071	1,261	370	557
2001	29,183	17,114	12,531	18,531	12,818	7,732	9,368	3,902	4,211	1,284	377	576
2002	30,933	18,365	13,138	19,643	13,755	8,106	9,930	4,187	4,414	1,361	404	604
2003	29,610	17,634	12,876	18,802	13,208	7,944	9,505	4,021	4,326	1,303	388	592
2004	29,527	17,731	13,031	18,749	13,281	8,040	9,478	4,043	4,378	1,299	390	599
2005	29,768	18,078	13,369	18,903	13,540	8,249	9,556	4,122	4,492	1,310	398	615
2006	30,504	18,749	13,892	19,370	14,043	8,572	9,792	4,275	4,668	1,342	412	639
TOTAL	603,337	356,889	247,293	383,119	267,310	152,580	193,671	81,371	83,091	26,547	7,852	11,375

Table 3.10. New Electrically Heated Homes Construction Forecast for the No Additional Action Alternative

	Regional Total			Climate Zone 1			Climate Zone 2			Climate Zone 3		
Year	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured
1986	25,133	13,693	9178	15,959	10,25	5,663	8,068	3,122	3,084	1,106	301	422
1987	30,183	16,754	10563	19,166	12,548	6,517	9,689	3,820	3,549	1,328	369	486
1988	26,989	15,908	10210	17,138	11,915	6,300	8,663	3,627	3,431	1,188	350	470
1989	25,655	20,087	11893	16,291	15,045	7,338	8,235	4,580	3,996	1,129	442	547
1990	21,345	17,015	11096	13,554	12,744	6,846	6,852	3,879	3,728	939	374	510
1991	21,471	17,558	11420	13,634	13,151	7,046	6,892	4,003	3,837	945	386	525
1992	19,122	15,642	10894	12,142	11,716	6,722	6,138	3,566	3,661	841	344	501
1993	18,834	15,756	11078	11,960	11,801	6,835	6,046	3,592	3,722	829	347	510
1994	19,233	16,659	11541	12,213	12,477	7,121	6,174	3,798	3,878	846	366	531
1995	18,029	16,000	11430	11,448	11,984	7,052	5,787	3,648	3,841	793	352	526
1996	18,276	16,310	11586	11,605	12,216	7,149	5,867	3,719	3,893	804	359	533
1997	18,361	16,297	11678	11,659	12,207	7,205	5,894	3,716	3,924	808	359	537
1998	18,761	16,757	11911	11,913	12,551	7,349	6,022	3,821	4,002	825	369	548
1999	18,384	16,350	11861	11,674	12,246	7,318	5,901	3,728	3,985	809	360	546
2000	18,645	16,662	12117	11,839	12,480	7,476	5,985	3,799	4,071	820	367	557
2001	19,064	16,934	12531	12,106	12,684	7,732	6,120	3,861	4,211	839	373	576
2002	20,331	18,172	13138	12,910	13,611	8,106	6,526	4,143	4,414	895	400	604
2003	19,550	17,450	12876	12,414	13,070	7,944	6,275	3,979	4,326	860	384	592
2004	19,505	17,546	13031	12,385	13,142	8,040	6,261	4,000	4,378	858	386	599
2005	19,641	17,889	13369	12,472	13,399	8,249	6,305	4,079	4,492	864	394	615
2006	20,118	18,552	13892	12,775	13,896	8,572	6,458	4,230	4,668	885	408	639
TOTAL	436,630	353,991	247,293	277,260	265,139	152,580	140,158	80,710	83,091	19,212	7,788	11,375

TABLE 3.11. New Energy-Efficient Homes Construction Forecast for the No Additional Action Alternative

	Penetration Rates			Climate Zone 1			Climate Zone 2			Climate Zone 3		
Year	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured	Single-Family	Multi-Family	Manu-factured
1986	0.15	0.15	0.01	2,394	1,538	57	1,210	468	31	166	45	4
1987	0.35	0.35	0.01	6,708	4,392	65	3,391	1,337	35	465	129	5
1988	0.45	0.45	0.01	7,712	5,362	63	3,899	1,632	34	534	157	5
1989	0.50	0.50	0.01	8,145	7,522	73	4,118	2,290	40	564	221	5
1990	0.60	0.60	0.01	8,132	7,647	68	4,111	2,328	37	564	225	5
1991	0.60	0.60	0.05	8,180	7,891	352	4,135	2,402	192	567	232	26
1992	0.60	0.60	0.08	7,285	7,029	538	3,683	2,140	293	505	206	40
1993	0.60	0.60	0.11	7,176	7,081	752	3,627	2,155	409	497	208	56
1994	0.60	0.60	0.14	7,328	7,486	997	3,704	2,279	543	508	220	74
1995	0.75	0.75	0.17	8,586	8,988	1,199	4,340	2,736	653	595	264	89
1996	0.75	0.75	0.21	8,704	9,162	1,501	4,400	2,789	818	603	269	112
1997	0.75	0.75	0.25	8,744	9,155	1,801	4,420	2,787	981	606	269	134
1998	0.75	0.75	0.29	8,935	9,413	2,131	4,517	2,865	1,161	619	276	159
1999	0.75	0.75	0.34	8,756	9,185	2,488	4,426	2,796	1,355	607	270	186
2000	0.75	0.75	0.38	8,880	9,360	2,841	4,489	2,849	1,547	615	275	212
2001	0.75	0.75	0.40	9,079	9,513	3,093	4,590	2,896	1,684	629	279	231
2002	0.75	0.75	0.42	9,683	10,208	3,405	4,895	3,107	1,854	671	300	254
2003	0.75	0.75	0.44	9,310	9,803	3,495	4,707	2,984	1,904	645	288	261
2004	0.75	0.75	0.46	9,289	9,856	3,698	4,696	3,000	2,014	644	290	276
2005	0.75	0.75	0.48	9,354	10,049	3,959	4,729	3,059	2,156	648	295	295
2006	0.75	0.75	0.50	9,581	10,422	4,286	4,843	3,172	2,334	664	306	320
TOTAL				171,963	171,062	36,864	86,929	52,072	20,075	11,916	5,025	2,748

TABLE 3.12. Number of Occupants per Dwelling Type per Year

Year	Single-Family	Multifamily	Manufactured Housing
1986	3.100	1.700	2.400
1987	3.100	1.700	2.400
1988	3.100	1.700	2.400
1989	3.100	1.700	2.400
1990	3.100	1.600	2.400
1991	3.000	1.600	2.400
1992	3.000	1.600	2.400
1993	3.000	1.600	2.300
1994	3.000	1.600	2.300
1995	3.000	1.600	2.300
1996	3.000	1.600	2.300
1997	3.000	1.600	2.300
1998	2.900	1.600	2.300
1999	2.900	1.600	2.300
2000	2.900	1.600	2.300
2001	2.900	1.600	2.300
2002	2.900	1.600	2.300
2003	2.900	1.600	2.200
2004	2.900	1.600	2.200
2005	2.900	1.500	2.200
2006	2.900	1.500	2.200

Source: BPA 1986a

3.6 INDOOR AIR QUALITY

There are many indoor pollutants and many potential sources of these pollutants. Every home contains pollutants that affect the quality of the indoor air. Some of the major pollutants are gases and particles generated when people use wood stoves and gas ranges or when they smoke. Some pollutants such as formaldehyde and other organic compounds are emitted by certain building materials, home furnishings, cleaning agents, and pesticides. Pollutants in the outdoor air can also contribute to poor IAQ. For example, carbon monoxide and nitrogen dioxide from automobile and industrial emissions can migrate indoors, as can radon from underlying soil.

Many factors affect the level and mix of pollutants found in a given home. Among these are source strength, house volume, occupant habits, and ventilation rates. One of these factors, ventilation rates, is also related to a building's energy efficiency. Blocking the pathways through which warm air leaves a home and cold air enters is an effective way to conserve energy. However, reducing the air flow between indoors and outdoors can also contribute to the buildup of indoor pollutant levels. Building energy-efficient homes with reduced ventilation does not cause indoor air pollution. Resulting pollutant levels depend on pollutant emissions inside the home or

TABLE 3.13. Affected Regional Population

	Climate Zone 1	Climate Zone 2	Climate Zone 3	Total
Single-Family				
Baseline				
1983 Practice	1,141,269	576,933	79,078	1,797,281
No Additional Action and Proposed Action				
1983 Practice	318,028	160,766	22,033	500,826
Energy-Efficient	510,905	258,274	35,403	804,582
Total	828,933	419,040	57,436	1,305,409
Multifamily				
Baseline				
1983 Practice	429,903	130,866	12,626	573,395
No Additional Action and Proposed Action				
1983 Practice	152,936	46,557	4,496	203,989
Energy-Efficient	273,533	83,263	8,034	364,830
Total	426,469	129,820	12,530	568,819
Manufactured Housing				
Baseline				
1983 Practice	352,297	191,851	26,262	570,410
No Additional Action and Proposed Action				
1983 Practice	268,936	146,453	20,045	435,435
Energy-Efficient	83,360	45,398	6,216	134,974
Total	352,296	191,851	26,261	570,410

the rates at which outside pollutants enter the home (e.g., through soil, air). In fact, some of the energy conservation measures may actually reduce pollution concentrations. For example, applied to the underside of the house, a correctly installed measure can reduce radon entry. Overall house tightening can also potentially reduce radon entry if it reduces the stack effect. But reduced air flows can trap pollutants present in the home, allowing them to build up instead of being diluted and dispersed to the outdoors.

In most homes, pollutant levels normally experienced are not dangerous or even noticeable. However, in some homes, pollutants build up or come from strong sources and may pose a hazard. People spend a large fraction of time in their homes, and long-term exposure to pollution may affect their health. Further, if people are especially sensitive, even low levels of pollution may cause some immediate physical reaction. There is sufficient theoretical and experimental evidence (based on individual homes) that reductions in air exchange rates cause increased indoor concentrations of pollutants for BPA to conclude that this is an important environmental concern of its New Energy-Efficient Homes Programs.

The discussion of IAQ is presented in two parts. Background information on factors such as source strength, ventilation, house volume, and health effects is presented in Section 3.6. How these factors interact with specific pollutants such as radon and formaldehyde is discussed in Section 3.7, Pollutant Characteristics.

3.6.1 Indoor Air Quality Dynamics

Pollutant concentrations in homes are determined by three key variables: house volume, pollutant source strength, and ventilation rates (or other removal mechanism rates). While house volume is a stable variable in that it does not change from one moment to the next, pollutant source strength and ventilation rates are influenced by many interacting factors.

Structure Volume

The volume of a structure is an important determinant of pollutant concentrations. With a given pollutant source strength and ventilation rate, a large-volume house will have a lower pollutant concentration than a smaller-volume house. The following prototypical volumes were assumed for houses in the region:

- single-family homes: 11,200 cubic feet
- multifamily homes: 6720 cubic feet per unit
- manufactured homes: 9360 cubic feet

Although the actual range of house volumes is large, these estimates give a fixed reference point, which is useful for studying the relationship between ventilation rates and pollutant source strength.

Source Strength

Sources may emit pollutants at a high or low rate; thus the source strength can vary. Depending on the nature of the source, emission rate can be influenced by temperature, humidity, quantity of the pollutant present, and installation and maintenance of appliances such as gas stoves. Factors that influence source strength are discussed for specific pollutants in Section 3.7, Pollutant Characteristics.

Ventilation

Indoor air pollutants and ventilation interact in such a way that when the source strength of pollutants and other factors are constant, which is rarely the case, a decrease in ventilation will increase the concentration of pollutants proportionately. In this inverse relationship, a 50% decrease in ventilation leads to the doubling of pollution levels. At lower ventilation rates, pollution levels will increase dramatically with even small drops in ventilation rates. This relationship is illustrated in Figure 2.4b. This one-to-one ratio may not hold true for radon, for a variety of reasons; e.g., the tightness of energy-efficient homes may actually block avenues for the entry of radon. This is discussed in more detail in Appendix B.

It is important to understand that air exchange rates in the same house may vary enormously from day to day and hour to hour; a house rarely has a single infiltration rate because weather conditions are rarely static. Similarly, the concentration of a pollutant changes over time because both the emission and removal rate of a pollutant varies over time and from house to house.

3.6.2 Health Effects

The concern is that these increased pollutant levels may adversely affect the health of exposed residents. Exposure is the amount of time a person is subjected to a specific pollutant level. Pollutant exposure can lead to both near-term and delayed, long-term health effects. Both can be produced by the same pollutant.

Early Health Effects

Even brief exposure to high concentrations of certain pollutants--carbon monoxide, nitrogen oxide, and formaldehyde, for example--can cause eye, nose, and throat irritation and respiratory problems. People may experience headaches, dizziness, or nausea. They may have difficulty breathing or find they tire easily. Symptoms vary, depending on sensitivity to a particular pollutant and the level of exposure. Generally, the greater the level of exposure, the greater the effect. Often these effects disappear when the source of the pollutant is removed.

Long-Term Health Effects

Delayed health effects from exposure to low pollutant levels over long time periods is also of concern. However, very little is now known about the effects of long-term exposure to low levels of pollutants found in homes. The picture is further complicated by the fact that people are exposed to many pollutants, so it is difficult to isolate and analyze the effect of any single pollutant.

Most of what is known about long-term health effects of pollutants comes from studies of workers exposed to high levels of pollutants on the job. These workers developed a range of medical problems including respiratory problems and cancer. But pollutant levels in the workplace were many times higher than those found in most homes.

For the purpose of this EIS we refer to long-term health effects as the estimated increase in lifetime cancer rates. Based on currently acceptable data, we are able to calculate lifetime cancer rates for only two of the indoor pollutants commonly found in homes: radon and formaldehyde. The risk factors we used for these two pollutants are presented in Section 3.7.

We assume there is a risk of developing cancer from long-term exposure to all levels of radon (lung) and formaldehyde (nasal). There is no acceptable threshold for exposure to either pollutant. Although little is known about the actual health effects of long-term exposure to low levels of these pollutants, risks of health effects at high concentrations can be used to estimate risks at low concentrations. This procedure requires making an assumption about the extrapolation of data from higher exposure levels to lower levels. Although other extrapolation techniques have also been proposed for estimating cancer rates from exposure to carcinogens, we use a linear extrapolation technique for estimating cancer rates from radon and formaldehyde, which is illustrated in Figure 3.6. Risk assessment models are described in the DEIS, Vol. II, Appendix B.

While linear extrapolation is a commonly used method to estimate the risk of lifetime cancer, such factors as variations in indoor pollutant levels, total amounts of exposure, and human responses to pollutant exposure make health effects difficult to estimate. Because there are large amounts of experimental data for radon, scientists have been able to develop a commonly accepted risk factor, which is considered conservative but which is weighted toward a value representative of average conditions. Little experimental data exist for formaldehyde, so we also use a conservative estimated risk factor to estimate the incidence of nasal cancer from this pollutant.

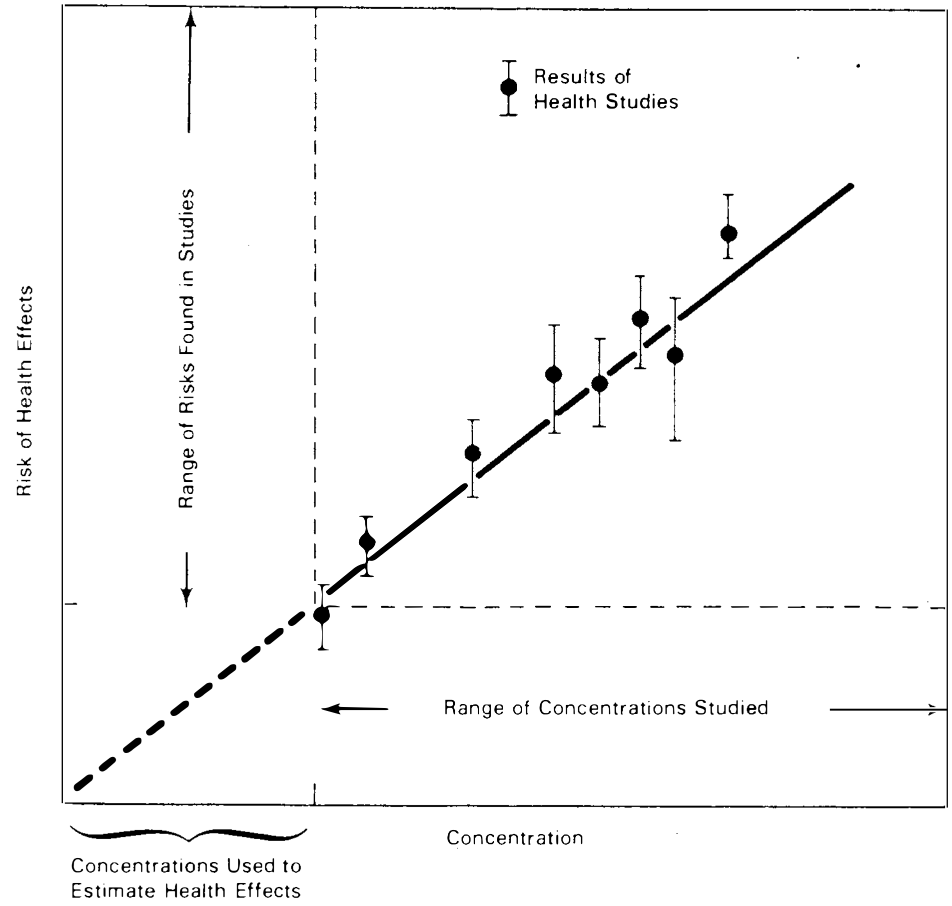


FIGURE 3.6. Example of Linear Extrapolation (BPA 1984, Page 3.12)

3.7 POLLUTANT CHARACTERISTICS

Information about specific pollutants commonly found in homes is given in this section. Radon and formaldehyde receive the most attention because we can estimate lifetime cancer rates for these pollutants in residential settings. Potential short-term health effects are qualitatively discussed for all pollutants included in this section, except radon, for which there is no evidence of short-term impacts. Although fiber glass has not been treated in this section, information on the health effects of fiber glass is included in Appendix J.

3.7.1 Radon

Radon is an odorless, colorless gas that comes from radium, a naturally occurring trace element in soil and rock. All rock and soils hold the base element, uranium-238, which decays to radium, which, in turn, decays to gaseous radon. The amount of radon gas present in the soil and the amount released by the soil vary widely. Radon gas quickly breaks down, or decays, into several radioactive elements, called radon daughters or progeny. Breathed in either directly or attached to dust specks, these progeny can adhere to the lung tissue, where they will emit radioactive particles which can give rise to lung cancer.

Measurements

Concentrations of radon gas are usually expressed in picocuries per liter (pCi/l). The curie (named after Pierre and Marie Curie, the discoverers of radium) is a measure of radiation. A picocurie is one-trillionth of a curie. A measurement of 1 pCi/l indicates the presence of one picocurie of radioactive material in one liter of air.

While levels of radon gas are expressed in pCi/l, concentrations of the radon decay products are generally expressed in working levels (WL), which are units designed for occupational exposure and represent the amount of alpha radiation released from the radon progeny to which an individual is exposed. A radon concentration of 1 pCi/l is generally equivalent to 0.005 WL, assuming that radioactive radon progeny amount to approximately 50% of radon gas. The cumulative exposure over time is expressed in terms of working level months (WLM), which represents the exposure to 1 WL over the course of an average working-month (170 hours).

Sources

In the Northwest, most radon found indoors comes from the soil beneath the foundations of buildings. Because it is a gas, radon is readily transported through cracks and holes in foundations. It also diffuses, although more slowly, through concrete. As radon travels upward, it enters buildings through cracks and openings in walls and floors. However, the precise means by which radon travels through the soil and enters structures is not well understood.

Scientists estimate that average soil contains about 1 pCi of radium per gram of soil (see Potential Health Effects of Certain Indoor Air Pollutants, Appendix B in Volume II of the DEIS). This supports an average soil surface emanation rate of about 0.5 pCi per square meter per second. This produces a steady-state outdoor concentration of about 0.2 pCi/l. Indoors, where the gas is confined rather than diluted, concentrations are about four times higher, or an average of about 0.8 pCi/l, although measured concentrations vary widely.

Well water may also be a source of radon. Unlike municipal water, well water is usually not exposed to the air before it is used indoors. When a faucet is turned on inside a home, radon in the water passes into the air. Natural gas, although it is considered a minor source, may also pick up radon in the ground and carry it into a home.

To some extent, building materials such as brick and phosphate slag may contain radium, which may decay to radon. Phosphate slag was used in insulation in residences in Washington. It was also widely used between 1962 and 1977 in the concrete foundations of homes built in southeastern Idaho (Diamond and Grimsrud 1984). Earthen homes and solar-heated structures with rock heat storage may also have high radon levels because of the additional earth and rock used in their construction. Sources of radon and pathways into a home are illustrated in Figure 3.7.

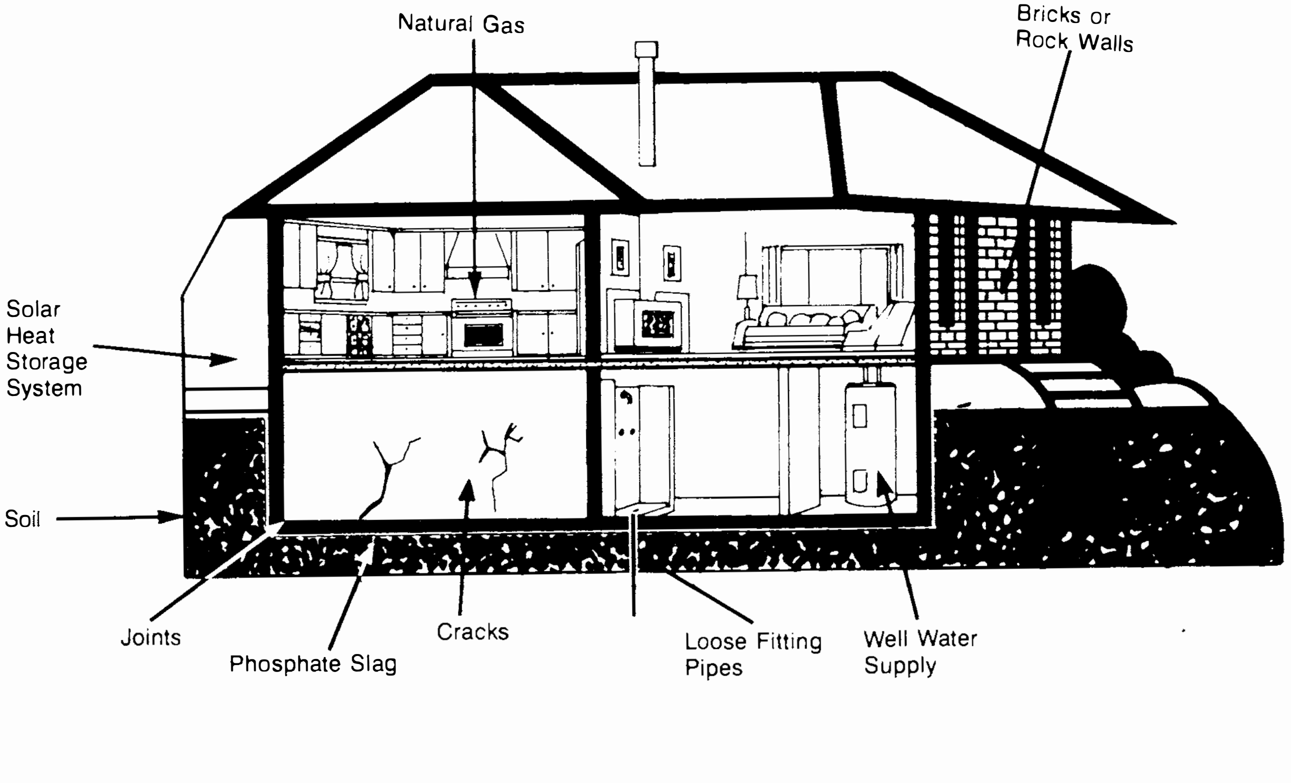


FIGURE 3.7. Radon Sources and Entry Paths

Standards

To date, no single standard for indoor radon has been established for residential housing throughout the United States. Guidelines have been set for some limited circumstances, and others have been proposed by various organizations, as shown in Table 3.14. Occupational guidelines are included for comparison.

In a recent report to Congress (EPA 1987a), EPA indicated that they plan to achieve their indoor air policy goals through non-regulatory approaches including research and development, information dissemination, and technical assistance and training. This decision indicates that risk information developed by EPA for exposure to radon in the indoor environment will be used only in the process of setting priorities with regard to their extensive activities. It also indicates that risk information will not be used for activities related to setting priorities for statutory requirements or in the design of regulations. For these activities, risk assessments are regarded only as providing for consistency and orderly decision-making (Travis et al. 1987).

Health Effects

Prolonged exposure to radon progeny increases the risk of developing lung cancer. Initial concern over increased public exposure to radon emerged from studies of uranium miners working for many years in high levels of radon. These miners developed lung cancer at a considerably higher rate than that of the general population.

Researchers are cautious about generalizing these risks to the entire population. The miners studied were generally exposed to levels many times higher than those found in the average home. Further, these miners, mostly adult males and cigarette smokers, do not represent a typical cross section of the general population. In addition, the mines were generally dusty, unventilated environments with many airborne particles, so it is possible that the combined effects of dust inhalation, smoking, and radon exposure, rather than just exposure to radon alone, led to the higher incidence of lung cancer. In their analyses, scientists have attempted to correct for differences between miners and the general population, but much uncertainty remains, and care must be taken to avoid combining small conjectured risks with well-demonstrated acute risks.

Because environmental exposures usually have been at low dose rates, experts do not agree on the appropriate extrapolations from miner data to environmental risk. In particular, the scientific community is not certain that there is a proportionate risk of lung cancer at very low levels of exposure. However, despite the uncertainties and assumptions, no better data base exists for inferring population risks. In addition, data from studies using animals exposed to radon support linearity between risks of cancer from exposure to high radon concentrations and risks at low concentrations. For calculating risk, the scientific community assumes that a linear relationship without threshold exists between radon exposure and the probability of lung

TABLE 3.14. Radon Standards and Guidelines

Organization	Level[a]		Comments
State of Pennsylvania	0.02 WL	4 pCi/l	Least critical suggested remedial action level
	0.1 WL	20 pCi/l	Take action in 3 weeks to 3 months
	0.5 WL	100 pCi/l	Take action within 2 weeks
	1.0 WL	200 pCi/l	Take action within 1 week
	>5.00 WL	>1000 pCi/l	Take action (relocate) within 2 to 3 days
American Society of Heating, Refrigerating and Air Conditioning Engineers	0.01 WL	2.0 pCi/l	Recommended indoor radon level
U.S. Environmental Protection Agency	0.02 WL	4 pCi/l	Level recommended for all homes.
Bonneville Power Administration	0.025 WL	5 pCi/l	Indoor radon action level for residential conservation programs
International Commission on Radiological Protection (ICRP)	0.054 WL	10.8 pCi/l	Pending recommended level in existing houses
	0.027 WL	5.4 pCi/l	Pending recommended level in new houses
U.S. Mine Safety and Health Administration	0.08 WL	16 pCi/l	Regulation for mines

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(a) WL converted to pCi/l assuming a 50% equilibrium between radon progeny and radon concentration.

Sources: Diamond and Grimsrud 1984; DEIS, Vol. II, Appendix B.

cancer. This type of relationship, diagrammed in Figure 3.6, was described in Section 3.6.

The lifetime absolute risk that applies to general populations is .0021 lung cancers per pCi/l. This is the same risk coefficient used in the BPA Expanded Weatherization Final Environmental Impact Statement and consistent with the ICRP and NCRP. This risk coefficient accounts for the age of occupants at exposure to increased levels of indoor radon and the increased mobility of populations. The probability that an individual will spend a lifetime in a particular house is very small. A 75% occupancy factor is assumed; the remainder of the time a person is outdoors or in other buildings.

Recently, the EPA produced a document (EPA 1986) that provides information on the relative risk, or range of expected risk factors, of radon and is based on assumptions made regarding the amount of time a person would be exposed to radon and the variety of the population that may be exposed. However, EPA's basic stance is that risk assessments do not give certainty in the scientific sense, nor can they be used to establish precise numbers of persons who will be stricken with some disease. Quantification is useful in risk assessment to approximate the magnitude of an effect, to set priorities, or to make comparisons (Russell and Gruber 1987).

Although it is not currently possible to assess the accuracy of risk projections for environmental exposure to radon, the scientific community is in general agreement about the absolute risk coefficient for exposure to radon daughters as advocated by NCRP and ICRP. BPA has elected to adopt this approach and has based the health effects analysis on the absolute risk coefficients. Appendix D provides an expanded discussion of risk assessment.

Radon Levels in Homes

The amount of radon that reaches the living space of a home depends partly on the home's characteristics. If there is a ventilated crawl space between the ground and the living area, some of the radon will escape outdoors. If the home's foundation or basement is flush with, or below, ground level, radon may pass readily through cracks and holes and enter the living space. Within an individual home radon levels can vary depending on the location of radon's point of entry and the ventilation rate.

To investigate radon levels in new homes in the Northwest, BPA monitored radon concentrations in approximately 400 homes built to 1983 practice and 400 energy-efficient homes. The monitoring results are summarized in Table 3.15, and these results reflect 12 months of data. A subset of these homes was also analyzed by scientists from Lawrence Berkeley Laboratory (LBL). Both studies concluded that, in general, building location was a more important determinant of radon concentration than was the energy efficiency of the house (BPA 1986c; Grimsrud et al. 1986). It should be noted that the energy-efficient dwellings were mechanically ventilated using AAHXs and had air exchange rates similar to those of the 1983 houses.

TABLE 3.15. Measured Radon Concentrations in RSDP Homes

Dwelling Type	Sample Size	Mean	Median	pCi/l Min.	pCi/l Max.	N>5 pCi/l
All	803	1.86	.70	.02	29.73	72
Energy-efficient	398	1.85	.62	.03	29.73	39
1983 practice	405	1.88	.73	.02	28.65	33
Zone 1, energy-efficient	255	.81	.40	.03	11.50	5
Zone 1, 1983 practice	283	.90	.44	.02	19.80	5
Zone 2, energy-efficient	74	3.12	1.62	.20	29.73	13
Zone 2, 1983 practice	51	3.39	1.88	.08	21.34	10
Zone 3, energy-efficient	69	4.36	3.06	.31	21.71	21
Zone 3, 1983 practice	71	4.71	2.99	.21	28.65	18

Source: BPA 1988a.

The study showed that the average radon level of all homes was 1.86 pCi/l, with a median of 0.70 pCi/l. For comparison, the mean of energy-efficient homes was 1.85 pCi/l and 1.88 pCi/l for 1983 homes. Only 72 homes out of 803, about 9%, had levels higher than 5 pCi/l. The distribution of concentrations based on the study is shown in Figure 3.8.

3.7.2 Formaldehyde

As an indoor air pollutant, formaldehyde is a colorless, water-soluble gas that has been linked with maladies ranging from minor irritation to nasal cancer. Formaldehyde is also a low-cost and versatile compound with excellent bonding characteristics, attributes that make it popular with manufacturers of building products, textiles, cosmetics, toiletries, and preservatives. Over the last 30 years, formaldehyde production and use has increased sixfold in the United States, from 1 billion pounds to about 6 billion pounds, but has leveled off over the last few years. About 50% of the compound goes to manufacture urea and phenol resins used in producing building materials such as particle board, plywood, and fiberboard.

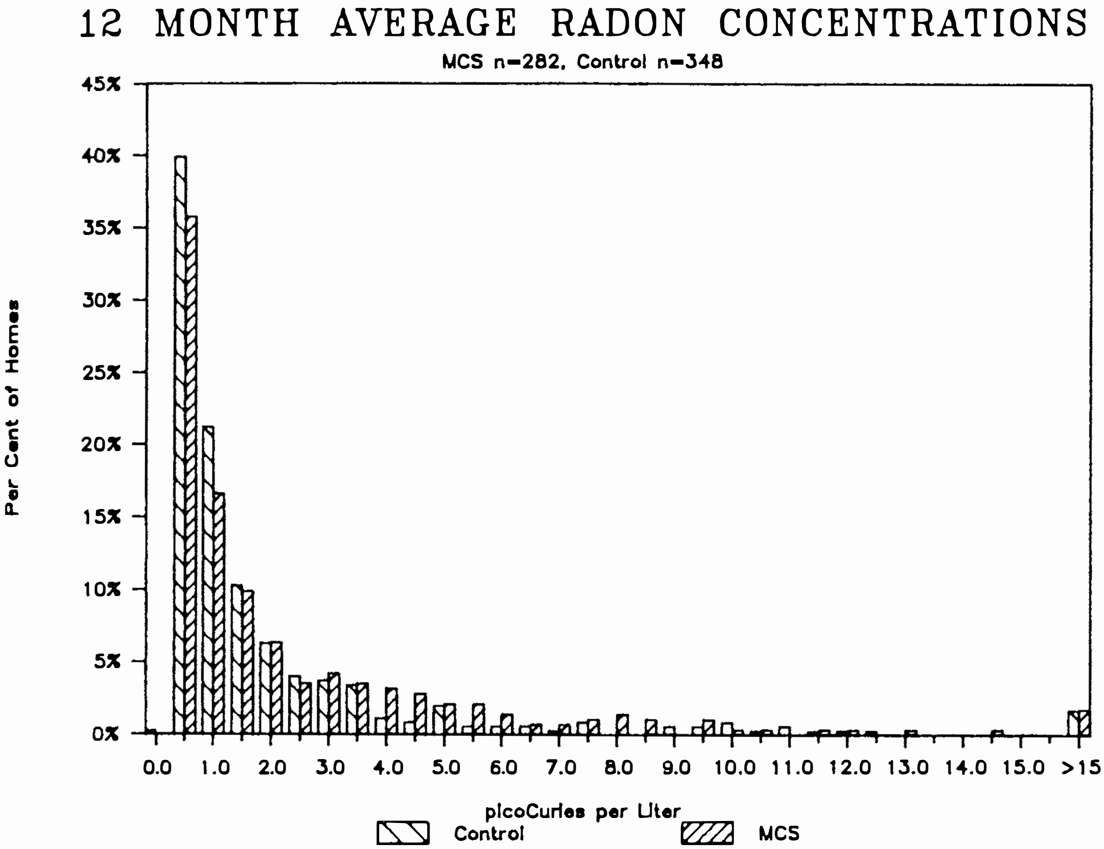

FIGURE 3.8. Distribution of Radon Concentrations in RSDP Homes (BPA 1986c)

Measurements

Formaldehyde levels in air are often given as parts per million (ppm). A measurement of 1 ppm would indicate the presence of one unit of formaldehyde in one million units of air. Levels are also reported as micrograms per cubic meter ($\mu g/m^3$), which indicates the amount of formaldehyde (in micrograms) present in one cubic meter of air. The conversion from one unit to the other is 1 ppm = 1200 $\mu g/m^3$.

Sources

Particle board, plywood, fiberboard, furniture, drapes, and carpeting are the primary sources of formaldehyde in new homes. Some formaldehyde is also produced during combustion, although gas stoves, wood stoves, and tobacco smoke are minor sources.

The rate at which formaldehyde is released from materials varies. As products containing formaldehyde age and cure, they emit less formaldehyde. Though the rate is not well defined, it appears that half of the formaldehyde contained in most materials is released in 2 to 5 years (Hawthorne, Matthews, and Gammage 1985). Formaldehyde emissions also increase with higher temperatures and humidity. Relatively high levels of formaldehyde are likely to be found in new homes, where materials have not had time to release much gas.

Formaldehyde emissions from a given source are also sensitive to levels present in the air. For example, if a new piece of furniture that emits formaldehyde is brought into a home that already has high formaldehyde concentrations, the new potential source will emit less gas, but over a longer period of time, than if it were brought into a home with low concentrations. Conversely, if increased ventilation rates exhaust formaldehyde gas from a structure, levels may not decrease as expected. Because the pollutant becomes less concentrated in the indoor air, sources may emit more gas to compensate (Matthews et al. 1983; Figley 1985).

Matthews et al. (1983) and Hawthorne, Matthews, and Gammage (1985) modeled the potential contribution from individual sources of indoor formaldehyde to concentrations in a single-family house. Although the source strength of any contributor depends on many variables that change with time and location, the estimates presented in Table 3.16 offer a basis for comparison in a laboratory situation. The estimates are based on a given area for each source, and the sources are categorized as those with direct exposure to the air and those covered with an effective barrier. For comparison, the tested emission rates of selected products are shown in Table 3.17.

Standards

The current HUD code for formaldehyde requires that levels not exceed a 0.4 ppm target in post-1984 HUD manufactured homes at an air exchange rate of 0.5 ACH, interior temperature of 77°F, and relative humidity of 50% (HUD 1984). The specific emission standards for particle board were set at 0.3 ppm and for interior plywood at 0.2 ppm, as measured by a specified air chamber test method. No standard has been established for formaldehyde concentrations in all residences. However, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 1981) has recommended 0.1 ppm as the maximum concentration for continuous indoor exposure. Formaldehyde standards, guidelines, and recommendations are listed in Table 3.18.

Health Effects

In 1984, a Consensus Workshop on formaldehyde convened scientists from academia, government, industry, and public interest groups to address the health effects of formaldehyde. Listed below are examples of data reviewed at the workshop. A more complete discussion of health effects and risk factors associated with formaldehyde is found in Potential Health Effects of Certain Indoor Air Pollutants, Appendix B in Vol. II of the DEIS.

- Formaldehyde gas is carcinogenic for rats and probably for mice, producing nasal tumors following inhalation exposure. In rats the carcinogenic response appears nonlinear, being disproportionately higher at higher concentrations (14 ppm).

TABLE 3.16. Potential Contribution of Solid Sources of Formaldehyde to Indoor Air in a Detached House

Product	Barrier	Area (m^2)	Contribution, ppm
Textiles	None	5	<0.01
Non-apparel		25	0.01
		5	<0.01
Apparel		25	
Carpeting		16	<0.01
Ceiling tiles	None	16	<0.01
Resilient flooring	None		
Furniture (uncovered board)		1.0	0.01
Industrial particle board		5.0	0.06
Medium-density	None	1.0	0.06
fiberboard		5.0	0.25
Decorative paneling	None		
Print overlay		10	0.11
Paper overlay		10	0.05
Domestic veneer overlay		10	0.05
Urea formaldehyde foam insulation	None	14	0.14
Particle board	None	16	0.16
Underlayment	Carpet & cushion	16	0.08
	Tile	16	<0.01
Softwood plywood Subflooring	Particle board Underlayment	16	<0.01
Carpet cushion	Carpet	16	<0.01
Fibrous glass ceiling insulation	Gypsum board	16	>0.01
Fibrous glass wall insulation	Gypsum board	14	>0.01

Source: Hawthorne, Matthews, and Gammage 1985.

TABLE 3.17. Formaldehyde Emissions from Selected Products

Product	Emission Rate (μg/g/day)
Particle board	0.4 to 8.1
Plywood	0.03 to 9.2
Paneling	0.84 to 2.1
Fiberglass insulations	0.3 to 2.3
Clothing	0.2 to 4.9
Drapery	ND to 3.0
Paper products	0.03 to 0.36
Carpet	ND to 0.06

ND = not detectable.

Source: Gupta, Ulsamer, and Preuss 1982.

- A substantial excess of human deaths from cancer of the brain is noted among three groups of professional workers who use formaldehyde on the job: embalmers, anatomists, and pathologists.
- Formaldehyde is genotoxic in a number of assays and is weakly mutagenic in human cells in culture as well as in other mammalian cells, Drosophila, fungi, and bacteria.
- Many reports state that formaldehyde vapor exposure causes direct irritation of the skin and respiratory tract. Within the range of 0.1 to 0.3 ppm, most people experience irritation of the eyes, nose, and throat. Between 10 and 20 ppm, symptoms are severe and breathing becomes difficult.
- Experiments in animals show that cellular damage and inflammation is induced with increasing severity at concentrations of 1 to 15 ppm.

As noted, studies have shown that formaldehyde can produce nasal cancer in animals. While there is no direct evidence that formaldehyde causes cancer in humans, a new risk assessment by EPA, based on nine studies, has characterized formaldehyde as a "probable human carcinogen" (EPA 1987b). The Risk Estimation Panel of the Consensus Workshop tried to determine how to use available data to make reasonable risk estimates for humans exposed to various levels of formaldehyde. While the panel did not offer potential quantification for any effect, it did endorse data from a rat inhalation chronic bioassay experiment conducted by the Chemical Industry Institute of Toxicology (CIIT) as suitable for modeling the human dose-response relationship.

In Bonneville's 1984 Expanded Weatherization Program Final EIS, calculation of annual and lifetime risk was based on the CIIT rat data (Cohn 1981, 1985). Cohn used a linear no-threshold dose response model to estimate the cancer risks. The model is as follows:

TABLE 3.18. Formaldehyde Standards, Guidelines, and Recommendations

Applicable Environment	Maximum Formaldehyde Level, ppm	Organization	Comment
Outdoor	0.1	American Industrial Hygiene Association	Recommended
	0.1	U.S. Environmental Protection Agency	Recommended
Indoor			
Occupational air	3.0	Occupational Safety and Health Administration	Standard (8-hr time-weighted average).
	2.0	National Institute of Occupational Safety and Health	Recommended (threshold limit value).
	1.0	National Institute of Occupational Safety and Health	Recommended (30-min maximum).
Nonindustrial	0.4	Wisconsin	Air quality standard in litigation.
	0.3	Minnesota	Particle board used in home construction standards.
	0.2	Minnesota	Plywood used in home construction standard.
	0.1	American Society of Heating, Refrigeration and Air Conditioning Engineers	Guideline.
	0.5	California	Recommended (Dept. of Health Services).[a]
Manufactured housing	<0.4	U.S. Department of Housing and Urban Development	

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[a] When used in manufactured housing, plywood is not to exceed 0.2 ppm and particle board 0.3 ppm, as measured by a specified air chamber test method. These product standards are targeted to provide an ambient level of 0.4 ppm or less in manufactured housing.

Sources: Sexton 1985; HUD 1984.

Upper value of human lifetime risk of contracting cancer =

0.00109 x exposure (average concentration [ppm] in residence)

For completing the analysis in the 1984 EIS we assumed maximum individual lifetime exposure to formaldehyde: a 9-year, 16-hour per day exposure for an average lifetime of 70 years.

For our analysis here, we again use Cohn's 1981 model, and the same assumptions, to estimate the lifetime cancer risk from exposure to formaldehyde. Several different models have been applied to risk assessments of potential carcinogens, the most widely used being the linear multistage procedures. Various estimates of cancer risk factors, obtained from the literature, are presented in Table 3.3 of Appendix B to the DEIS. These estimates have been derived using the multistage and other models. The risk factors vary because of the large uncertainties inherent in risk assessments. Even though these models are based on the same CIIT rat data, they vary according to assumptions used, such as animal exposure concentrations, mathematical techniques, and extrapolation of animal data to human risk. Furthermore, there are no scientific criteria for choosing one model over another, and there is no basis for declaring that one model is better than the next. We chose Cohn's 1981 model because (1) it permits comparability with BPA's 1984 Expanded Weatherization Program Final EIS, and (2) it yields conservative results, that is, higher cancer rates, and is thus more appropriate for a planning document.

Short-term health effects associated with formaldehyde are described qualitatively in Table 3.19. Insufficient information is available to quantify these effects, partly due to differences in individual sensitivity to the pollutant.

Formaldehyde Levels in Homes

Because of the range of available products containing formaldehyde, it is impossible to predict what level of formaldehyde would be found in a given home. Onsite measurements would be necessary. If a home has a high level of formaldehyde, the occupants are likely to be aware of it. Most people notice the strong odor of formaldehyde at about 1 ppm. Some people can smell formaldehyde at much lower concentrations.

As part of the RSDP, Bonneville monitored formaldehyde concentrations in homes built to 1983 practice and in energy-efficient homes. In 1984-85, 573 homes were monitored; in 1985-86, 631 homes. The average concentrations of formaldehyde in these homes are given in Table 3.20. The distribution of formaldehyde concentrations based on the study is shown in Figure 3.9.

In a related experiment, BPA took measurements in a subsample of these homes, all less than 5 years old, to investigate the effect of time, or dwelling age, on formaldehyde levels. Two sets of measurements were taken in 341 single-family homes. The first measurements were taken in the winter of 1984-1985; the same houses were monitored again a year later. The results

TABLE 3.19. Short-Term Health Effects Associated with Formaldehyde Exposures in Residential and Occupational Studies

Formaldehyde Concentration, ppm	Health Effects	Exposure Setting
0.0 to 10	Nausea; eye, nose, and throat irritation; headaches; vomiting; stomach cramps	Residential
0.02 to 4.15	Diarrhea, eye and upper respiratory tract irritation, headaches, nausea, vomiting	Residential
0.09 to 5.6	Burning of eyes and nose; sneezing, coughing and headaches; 3 of 7 suffered from asthma or sinus problems	Occupational
0.3 to 2.7, Av 0.68 Median 0.4	Annoying odor, constant pricking of mucous membranes, disturbed sleep, thirst, heavy tearing	Occupational
0.13 to 0.45	Burning and stinging of eyes, nose, and throat, headaches	Occupational
0.2 to 0.45 Av 0.36	Irritation of eyes and upper respiratory tract, drowsiness, headaches, and menstrual irregularities	Occupational
0.13, 0.57, and 0.44	Headaches, concentration problems, dizziness, nausea, coughing, increases in recurring infections of the upper respiratory tract, and irritation of eyes, nose, and throat	Schools
0.83	Loss of olfactory sense, increased upper respiratory disease, subatrophic and hypertrophic alterations in nose and throat, ciliostatis of nasal mucosa, increased adsorptive function of nasal mucosa	Occupational (greater than 5 years to less than 10 years)
0.9 to 1.6	Itching eyes, dry and sore throat, disturbed sleep, unusual thirst upon awakening in the morning	Occupational
0.9 to 2.7	Tearing of eyes, irritation of nose and throat	Occupational
Unknown	Chronic airway obstruction, respiratory tract and eye irritation, small decrease in pulmonary function during work day and work week	Occupational
1.3 to 3.8	Menstrual disorders, pregnancy complications, low birth weight of offspring	Occupational

Source: Gammage and Gupta 1984; Gammage, White and Gupta 1984.

TABLE 3.20. Mean Values for Formaldehyde Concentrations Measured in RSDP Homes

	1984-85		1985-86	
Dwelling Type	Number of Observations	Mean Concentration, ppm	Number of Observations	Mean Concentration, ppm
All homes	577	.10	640	.09
All energy-efficient	207	.11	395	.08
All 1983 practice	370	.09	245	.09
Zone 1, energy-efficient	103	.11	262	.09
Zone 1, 1983 practice	254	.09	173	.09
Zone 2, energy-efficient	41	.10	72	.07
Zone 2, 1983 practice	47	.08	34	.09
Zone 3, energy-efficient	63	.12	61	.09
Zone 3, 1983 practice	69	.10	38	.08

Source: BPA 1988a.

are shown in Table 3.21. Of these homes, 167 were new energy-efficient houses. The remaining 174 were control houses built using 1983 practices.

The median formaldehyde concentration across all dwelling types the first year was 0.103 ppm, just slightly greater than the ASHRAE recommendation of 0.1 ppm, and 0.082 the second year. In 1984-85, the median level measured in control homes was 0.102 ppm, and 0.104 in energy-efficient homes, not a statistically significant difference. Levels dropped to 0.084 ppm in control houses and to 0.079 in energy-efficient houses in 1985-86. This represents a 20% decrease in formaldehyde concentrations in both types of houses. These results indicate that the age of a house is the primary factor controlling formaldehyde concentrations in both houses built using 1983 construction practices and energy-efficient homes.

Formaldehyde was also measured in five demonstration manufactured homes in spring 1986, only 8 to 9 weeks after construction. Each home has low formaldehyde-emitting products exactly as would be included in a typical post-1984 HUD manufactured home. Formaldehyde levels were calculated for the time the AAHX was operating, along with the average air exchange rate, average interior temperature, and average relative humidity (BPA 1986h); Parker and Onisko 1986). The measurements are given below.

Formaldehyde: 0.076 ± 0.02 ppm
Air Exchange Rate: 0.52 ± 0.12 ACH
Relative Humidity: 52%
Interior Temperature: 83°F

The air exchange rate and interior humidity levels were near those used by HUD in their guidelines. The interior temperature was elevated and could cause some, though not significant, elevation in levels of formaldehyde. The effect of occupancy (e.g., furniture, smoking) is estimated to add, on average, an additional 10-25% to the measured formaldehyde levels (Walsh, Dudney, and Coenhaver 1984). However, most of this increase contributed by occupancy could be offset by the materials in the home (paneling, particle board, carpet and draperies) having aged by the time of the tests.

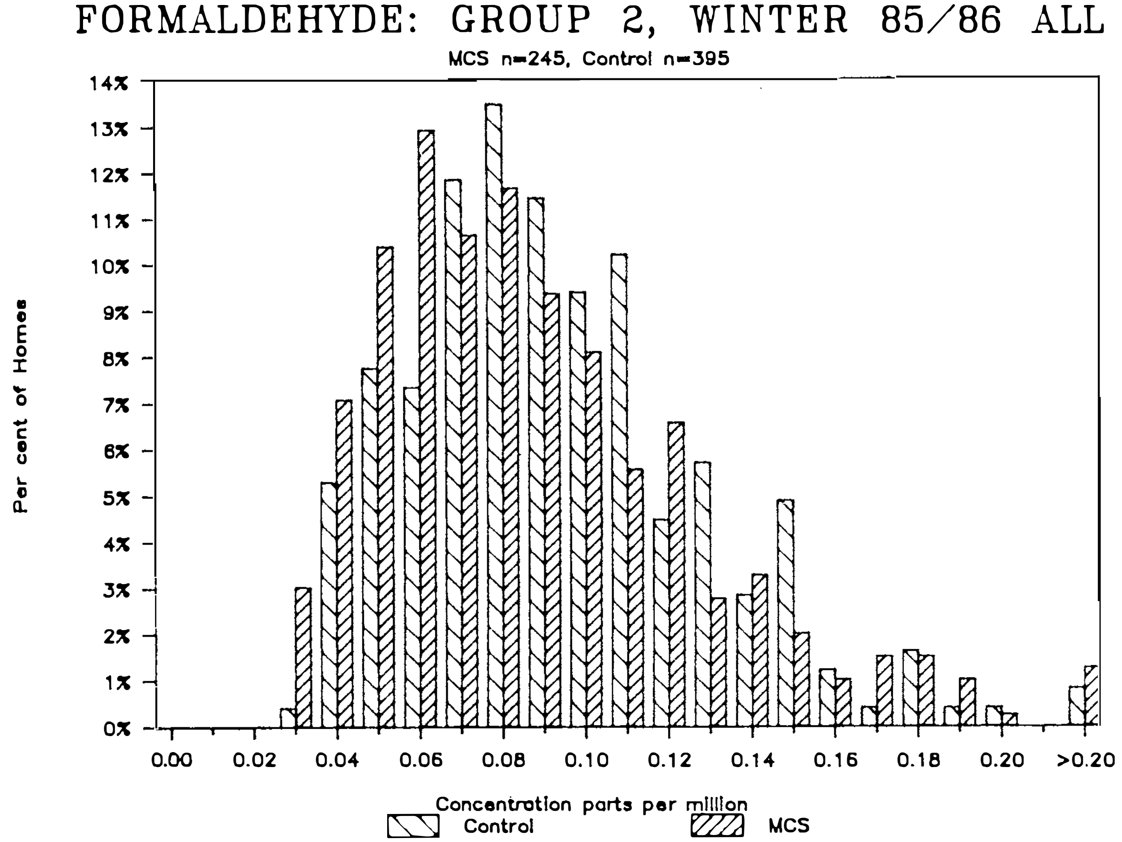

FIGURE 3.9. Distribution of Formaldehyde Concentrations in RSDP Homes (BPA 1986f)

TABLE 3.21. Measured Formaldehyde Concentrations in Subsample of RSDP Homes

Dwelling Type	Number of Observations	1984-85 Median Concentration, ppm	1985-86 Median Concentration, ppm
All homes	341	.103	.082
Energy-efficient	167	.104	.079
1983 practice	174	.102	.084
Zone 1, energy-efficient	81	.102	.087
Zone 1, 1983 practice	116	.104	.087
Zone 2, energy-efficient	35	.095	.066
Zone 2, 1983 practice	23	.087	.084
Zone 3, energy-efficient	51	.116	.080
Zone 3, 1983 practice	35	.104	.080

Source: BPA 1988a.

3.7.3 Respirable Suspended Particulates

Respirable suspended particulates (RSP) are the smallest particles or fibers suspended in the air. Common thresholds for definition are given at less than 10 micrometers in diameter. When inhaled, these particles can lodge in the deepest parts of the lungs. Particles of all sizes suspended in the air are referred to as total suspended particulates (TSP). Tobacco smoke, benzo-[a]pyrene (BaP), and asbestos are examples of compounds that may make up RSP.

Measurements

Measurements of RSP are given as micrograms (one-millionth of a gram) per cubic meter ($\mu g/m^3$). Benzo[a]pyrene (BaP) is measured in nanograms (one-billionth of a gram) per cubic meter (ng/m^3).

Sources

Since exposure to asbestos is unlikely to occur in new homes, we provide only a brief description of this pollutant. Asbestos is a mineral fiber used primarily before the mid-1970s in a variety of construction materials. While chronic exposure to asbestos has led to respiratory diseases and cancer in workers, exposure to asbestos in the home occurs only when asbestos materials are disturbed and the fibers are released into the air. The EPA, the Consumer Product Safety Commission, and manufacturers have taken steps to reduce exposure to asbestos. In the mid-1970s these groups prohibited or voluntarily stopped using asbestos in sprayed-on insulation, fire protection, sound-proofing, pipe coverings that easily crumble, artificial logs, patching compounds, and hand-held hair dryers.

Tobacco smoke contains about 3800 compounds and is the source of most RSPs in homes with people who smoke. Wood smoke, unvented gas appliances, and kerosene space heaters also produce RSP. Wood and cigarette smoke are the major sources of BaP.

Wood stoves and fireplaces are likely to emit pollutants, such as BaP, under the following conditions: improper stove installation (e.g., insufficient stack height, poor flue fittings, or leaky doors); when the fire is stoked or fuel is added; during accidents (e.g., a log rolls out of the fireplace); when the fire is allowed to smolder; or when negative indoor air pressure results in backdraft.

Standards

Currently, there is no standard for RSP, although EPA has a standard for TSP in outdoor air. The TSP include larger particles as well as RSP. Because larger particles appear to be filtered out by the nasal passages rather than becoming lodged in the lungs, they are believed to not pose as serious a health problem. The EPA standard for the maximum allowable annual average level of TSP in outdoor air is 75 $\mu g/m^3$. Japan has set an indoor, non-occupational standard for TSP of 150 $\mu g/m^3$.

Health Effects

Particulates are composed of many compounds that, at elevated levels, can irritate eyes and mucous membranes. Dust is an irritant and can also carry gases or other substances into the lungs. Respiratory illnesses, especially chronic illnesses like bronchitis and emphysema, are linked to exposure to particulates (Diamond and Grimsrud 1984).

Cigarette smoking is believed to cause lung cancer, emphysema, and heart disease. According to recent studies, tobacco smoke may affect the health of nonsmokers as well. However, it is not possible to directly extrapolate from the health effects of active to those of passive smoking.

In a room where cigarettes are smoked, sidestream smoke inhaled by nonsmokers can irritate the eyes, nose and throat, and cause coughing and headaches. But these effects are short-term and generally disappear when the offense is removed.

Of greater concern than these nuisance and transient effects are potentially more serious chronic health effects. For example, some researchers have observed a higher incidence of respiratory illness in children whose parents smoke. Sidestream smoke may also cause respiratory infections and can aggravate the condition of people who have allergies or heart or lung disease. Studies have also found respiratory cancer in nonsmokers married to smokers, but these studies are controversial and currently inconclusive. Given that 60% of the population is chronically exposed to passive smoking, this issue will continue to be an important subject for investigation. However, it is not now possible to meaningfully assess the risk associated with exposure to passive smoke. Appendix K reviews the more recent literature on environmental tobacco smoke, including the Surgeon General's 1986 report on involuntary smoking.

Benzo[a]pyrene, a combustion by-product, is a tarry, organic RSP generated by incomplete combustion. In BPA's Expanded Weatherization FEIS, analysts assumed that the potential carcinogenicity of complex mixtures, including cigarette smoke and woodburning appliance emissions, could be estimated on the basis of the mixtures' BaP content. The carcinogenicity of BaP in mixtures was assumed to be similar to that of BaP in its pure form. Recent evidence suggests that these assumptions are no longer valid.

A review of available information suggests the following conclusions about the health effects of BaP:

- Benzo[a]pyrene is a procarcinogen.
- Benzo[a]pyrene and its metabolites and derivatives can range from being biologically inactive to highly active and carcinogenic.
- The more complex the mixture containing BaP, the more likely that its carcinogenicity will be masked or inhibited.
- The carcinogenicity of mixtures containing BaP does not vary directly with BaP content.
- The biological activity of BaP can vary greatly in strains of the same species and from person to person.

Benzo[a]pyrene is an important and common pollutant in indoor air. However, scientific knowledge about the relationship between BaP exposure and increased numbers of human cancers is imprecise. Given the uncertainty and variation associated with the health effects of BaP, it would be simplistic to use a single dose-response model to estimate lifetime cancer risk from BaP.

Respirable Suspended Particulate Levels in Homes

Concentrations of RSP in homes where there are no smokers are likely to be about the same as outdoor levels: 20 $\mu g/m^3$ (NRC 1981). Monthly concentrations of RSP in a home with one smoker have been measured at about 40 $\mu g/m^3$ (NRC 1981). In the same study, with two or more smokers, an average monthly concentration of RSP was measured at 75 $\mu g/m^3$, equal to the EPA outdoor standard for all particulates. Cigarettes are made up of about 3800 compounds, making their smoke a complex mixture of interacting pollutants. Concentrations of some of the constituents of tobacco smoke are presented in Table 3.22.

3.7.4 Combustion Gases: Carbon Monoxide and Nitrogen Oxides

Carbon monoxide is a colorless, odorless gas. It is a product of incomplete combustion when natural gas, oil, wood, coal, tobacco, and other materials are burned. Carbon monoxide increases when there is an inadequate supply of combustion air, as is often found in improperly maintained wood stoves, gas stoves, oil stoves, and furnaces. The nitrogen oxides and nitrogen dioxide are gases formed during combustion.

Measurements

Carbon monoxide measurements are often given in parts per million (ppm). A measurement of 1 ppm would indicate the presence of one unit of carbon monoxide in one million units of air.

Oxides of nitrogen measurements are also often given as ppm. Under ambient conditions, nitrogen oxide quickly oxidizes to nitrogen dioxide, so the standards for nitrogen oxides are often given as nitrogen dioxide. Because the oxidation process of nitrogen oxide to nitrogen dioxide is slow indoors, elevated nitrogen oxide levels occur.

Sources

Unvented kerosene space heaters, wood stoves, gas stoves, and tobacco smoke are major sources of carbon monoxide. Faulty furnaces and exhaust fumes from garages attached to homes may also contribute significant amounts of carbon monoxide to indoor air.

The major sources of nitrogen oxide and nitrogen dioxide are unvented gas stoves and kerosene space heaters. High outdoor levels of nitrogen dioxide, found in highly industrialized areas, can also affect indoor levels.

Standards

No federal or state standards exist for carbon monoxide in residences. Japan, the only country with a standard for carbon monoxide in non-occupational indoor environments, has set a limit of 10 ppm for continuous exposure. The EPA (1979) standard for maximum allowable level of carbon monoxide in outdoor air is 9 ppm, averaged over 8 hours, and 35 ppm for a 1-hour average exposure. This standard has a safety margin built in to

TABLE 3.22. Concentrations of Tobacco Smoke Constituents Under Experimental and Natural Conditions (DEIS, Vol. II, App. B, Table 5.9)

Constituent	Location	ACH	Tobacco Burned	Concentration
		Experimental Conditions		
Carbon monoxide	80-170 m^3 rooms	6.4-2.3	46-101 cigarettes	4.5-75 ppm
	Small car, 25 m^3 chamber	None	4-9 cigarettes	12-110 ppm
Nicotine	57-80 m^3 rooms	6.4-8.2	42 cigarettes, 9 cigars	<0.1-0.42 mg/m^3
	38-170 m^3	None	10 cigarettes, 9 cigars	0.13-1.04 mg/m^3
Total particulate matter	15-425 m^3 homes	1-3	7-35 cigarettes	1.1-3.0 mg/m^3
	25 m^3 chamber	None	4-24 cigarettes	2.28-16.65 mg/m^3
Dimethylnitrosamine	4-m^3 box, 20 m^3 room	None	10-100 cigarettes	0.23-2.9 μg/m^3
Acrolein	30-170 m^3 rooms	None-2.4	5-150 cigarettes	0.02-0.29 ppm
Acetaldehyde	38-170 m^3 rooms	None-2.4	5-150 cigarettes	0.06-0.56 ppm
Formaldehyde	30 m^3 box	None	5-10 cigarettes	0.23-0.46 ppm
Nitric oxide	30 m^3 box	None	5-10 cigarettes	0.19-0.36 ppm
Nitrogen dioxide	30 m^3 box	None	5-10 cigarettes	0.02-0.04 ppm
			Natural Conditions	
Carbon monoxide	Office, restaurant club, tavern, arena			2.5-28 ppm
	Submarine, boat, autos, bus, airplane	None-20	4-150 cigarettes	3-33 ppm
Nicotine	Submarine, terminal, restaurant		Up to 150 cigarettes	-35 mg/m^3
Total particulate matter	Tavern, arena	None-6		0.15-0.98 mg/m^3
Particles	House		1 cigar	48 x 106 particles/m^3
Benzopyrene	Arena			0.0071-0.21 μg/m^3
Dimethylnitrosamine	Bar			0.11-0.24 μg/m^3
Respirable particulate matter	Restaurants, sports arena, bowling alley			100-700 μg/m^3

protect people with angina (NRC 1981). These people have inadequate blood and oxygen flow to the heart, so they are especially sensitive to any interference with the body's ability to absorb or distribute oxygen.

The U.S. Occupational Safety and Health Administration (OSHA) has set workplace standards of 5 ppm for nitrogen dioxide and 25 ppm for nitrogen oxide for average exposure over 8 hours. The EPA standard for maximum allowable concentration of nitrogen dioxide in outdoor air is 0.056 ppm averaged over 1 year.

Health Effects

Because carbon monoxide combines with hemoglobin in the blood 220 to 250 times more readily than oxygen, it interferes with the delivery of oxygen throughout the body. Mild oxygen deficiencies can affect vision and brain function. Exposure to concentrations of carbon monoxide 10 to 20 times greater than that generally found in homes can cause headaches and irregular heartbeat. Higher concentrations can cause nausea, weakness, confusion, and death. Carbon monoxide poisonings from faulty oil and gas furnaces and from cars left running in attached garages cause several deaths each year (Spangler and Sexton 1983).

Unborn children, anemic people, and those with respiratory problems are especially endangered by exposure to carbon monoxide. The acute health effects of carbon monoxide exposure are summarized in Table 3.23.

Nitrogen oxide and nitrogen dioxide can irritate skin, eyes, and mucous membranes. Depending on the level and duration of exposure, respiratory effects range from slight irritation, to burning and pain in the chest, to violent coughing and shortness of breath (BPA 1984). Both compounds also reduce the oxygen-carrying capacity of blood. The physiological effects of nitrogen oxide at 3 ppm are similar to those of carbon monoxide at 10 to 15 ppm.

Oxides of nitrogen can cause acute and chronic changes in the small airways and lungs. In healthy humans, respiratory functions generally are not affected at levels of 1.5 ppm nitrogen dioxide or below. But sensitive individuals can experience respiratory tract irritation at 0.5 ppm nitrogen dioxide. Children and persons with asthma, chronic bronchitis, and emphysema appear to be the most sensitive. Persons with hay fever, or liver, hematological, or hormonal disorders can also be affected by low levels, but data are too sparse for recommending exposure limits. An overview of the effects of short-term exposure to nitrogen dioxide is given in Figure 3.10.

Carbon Monoxide Levels in Homes

The average carbon monoxide concentration in homes typically varies between 0.5 and 5 ppm (NRC 1981). Cooking over a gas stove can add 5 to 10 ppm to the existing level (Spangler and Sexton 1983). Concentrations of 22 ppm and 39 ppm have been measured for poorly adjusted gas stoves (Meyer 1983).

TABLE 3.23. Acute Health Effects of Carbon Monoxide Exposure

Atmospheric CO, ppm	Carboxyhemoglobin, Concentrations, %	Principal Symptoms
10 to 30	2.5 to 5	Encroachment of functional reserve of heart and brain
50	7 to 8	Slight headache in some
100	12 to 15	Moderate headache and dizziness
250	25	Severe headache and dizziness
500	45	Nausea, headache, possible collapse
1,000	50 to 60	Coma
10,000	95	Death

Source: Forbes 1972.

Unvented gas or kerosene heaters can emit high levels of carbon monoxide. In laboratory tests, a convective kerosene heater produced carbon monoxide levels of 50 ppm after 45 minutes, even though the laboratory air change rate was twice that found in a typical house (Diamond and Grimsrud 1984). Several states have banned residential use of kerosene heaters.

Nitrogen Oxides Levels Found in Homes

Nitrogen dioxide concentrations equal to or greater than the EPA standard for outdoor air (0.05 ppm) are fairly common in kitchens where gas is used for cooking (NRC 1981). Measurements indicate that typical levels in kitchens with gas stoves range from 0.025 to 0.08 ppm (Quackenboss et al. 1982). Concentrations in homes without gas appliances would be about the same as the outdoor level. In the Northwest, the typical outdoor level of nitrogen dioxide is 0.03 ppm, though levels vary with location (BPA 1984).

Nitrogen dioxide in the outdoor air is largely the result of motor vehicle and industrial emissions. In a study of 61 electrically heated Northwest residences, oxides of nitrogen concentrations ranged from 0.4 to 6.8 ppb.

Unvented space heaters are major sources of nitrogen dioxide. In laboratory tests, nitrogen dioxide concentration from a convective kerosene space heater reached 1 ppm after 45 minutes--about 20 times the EPA standard for outdoor air (Diamond and Grimsrud 1984).

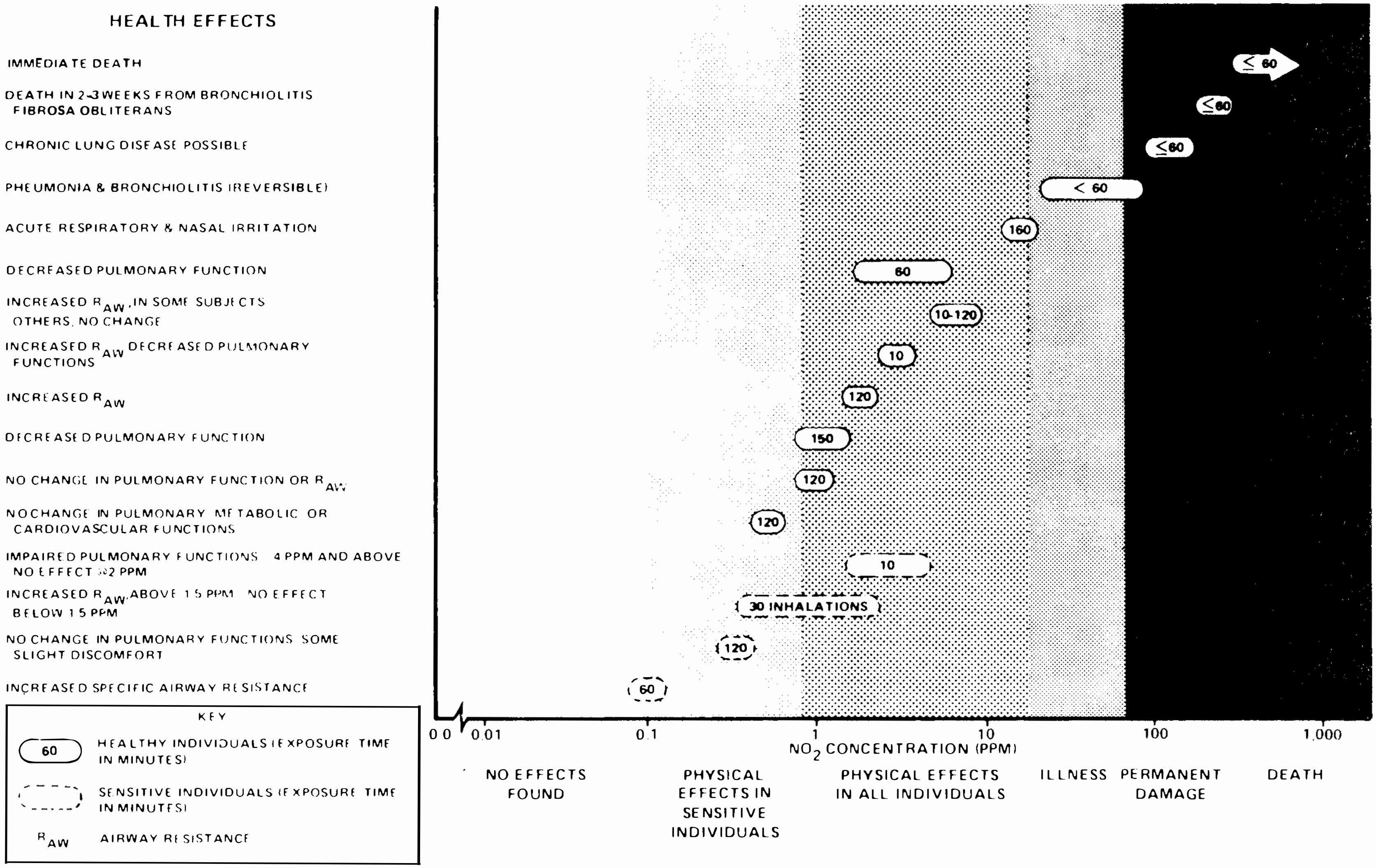

FIGURE 3.10 Effects of Short-Term Exposures to Nitrogen Dioxide (NO2) in Healthy and Sensitive Humans (DOE 1985)

3.7.5 Household Chemicals

Many of the chemicals used in household cleaners, pesticides, and materials contain toxic substances. Many of these chemicals are organic compounds containing carbon as their primary element. The pollutants can exist as gases, vapors, or particulates.

Sources

Many potentially hazardous chemical compounds are used in house construction, home maintenance, and personal hygiene. More than 350 organic compounds have been found in concentrations over 0.001 ppm in indoor air (Sterling 1984). These compounds are part of almost all materials and products in use, as illustrated by the following examples:

- Synthetic materials used in carpeting, wall covering, linoleum, fabrics, rubber, and plastic emit organic compounds as they age and deteriorate.
- Adhesives, cleaning agents, paints, personal hygiene products, and waxes contain solvents that evaporate into the air.
- Natural gas, tobacco, wood, and other materials emit organic gases and particles during combustion.
- Pesticides, insecticides, and herbicides contain a variety of toxic chemicals.
- Aerosol sprays contain propellant gases, such as propane, butane, and nitrous oxide.

Normal human and pet biological processes result in the emission of organics called bioeffluents. Prevalent among them are methanol, ethanol, acetone, and butyric acid. In studies of students in classrooms, some of these emissions increased markedly during times of stress such as examinations.

Standards

Examples of organic compounds regulated in workplace settings but often found in households are given in Table 3.24.

Health Effects

Household chemicals contain such a wide variety of organic compounds that health effects are difficult to assess. Each compound has different effects and, when products are combined, they may interact and produce still other health effects. Some compounds are irritants; others are carcinogenic. Some affect the central nervous system, and some interfere with metabolic processes. Health effects of some organics commonly found in indoor air are shown in Table 3.25.

TABLE 3.24. Occupational Exposure Limits of Organics That May Be Found in Homes

Chemical	TLV-TWA,(a) mg/m3, ppm	TLV-Stel,(b) mg/m3, ppm	Source
Acetone	1780 (750)	2375 (1000)	Lacquer solvent
Ammonia	18 (25)	27 (35)	Cleaner
Benzene	30 (10)	75 (25)	Adhesive, spot cleaner, paint remover
Carbon tetrachloride cleaner	30 (5)	125 (20)	Spot cleaner, dry
Chlorine	3 (1)	9 (3)	Cleaner
Methanol	260 (200)	310 (250)	Paint, spot cleaner
Trichloroethane	1900 (350)	2450 (450)	Cleaning fluid
Methylene chloride	350 (100)	1740 (500)	Paint remover
Trichloroethylene	270 (50)	805 (150)	Dry-cleaning agent
Turpentine	560 (100)	840 (150)	Paint, finish
Xylene	435 (100)	655 (150)	Solvent, paint carrier, shoe dye
Toluene	375 (100)	560 (150)	Solvent, paint carrier, dry cleaning

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(a) Long-term average maximum exposure limit; TLV=time limiting value; TWA= time-weighted average.
(b) Short-term maximum exposure limit.
Source: ACGIH (1983)

Concentrations Found in Homes

Concentrations of specific organic compounds in homes are generally well below occupational exposure levels established by OSHA, but are often well above levels found outdoors. The OSHA standards were designed for industrial settings where workers are exposed to high levels of single compounds. In homes, people are likely to be exposed to low concentrations of several compounds at the same time. As yet, researchers know very little about the combined effects of organic compounds or the effects of low-level exposure over long time periods.

TABLE 3.25. Sources, Uses, and Potential Health Effects of Organics Commonly Found in Indoor Air

Compound	Sources and Uses	Potential Health Effects
Formaldehyde and other aldehydes	Outgassing from building materials (particle board, plywood and urea-formaldehyde insulation foam); also from cooking and smoking.	Eye and respiratory irritation; possibly more serious long-term health effects.
Benzene	Plastic and rubber solvents; from cigarette smoking; in paints and varnishes, including putty, filler, stains and finishes.	Respiratory irritation; recognized carcinogen.
Xylene	Solvent for resins, enamels, etc.; in non-lead automobile fuels and in manufacture of pesticides, dyes, pharmaceuticals.	Narcotic; irritating; in high concentrations, possibly injurious to heart, liver, kidney and nervous system.
Toluene	Solvents; by-product of organic compounds used in several household products.	Narcotic; may cause anemia.
Styrene	Widespread use in manufacture of plastics, synthetic rubber, and resins.	Narcotic; can cause headache, fatigue, stupor, depression, incoordination and possible eye injury.
Trichloroethane	Aerosol propellant, pesticide, cleaning solvents.	Subject of Occupational Safety and Health Administration carcinogenesis inquiry.
Trichloroethylene	Oil and wax solvent, cleaning compounds, vapor degreasing products, dry-cleaning operations; also as an anesthetic.	Animal carcinogen; subject of OSHA carcinogenesis inquiry.
Ethyl benzene	Solvents, in styrene-related products.	Severe irritation to eyes and respiratory system.
Chlorobenzenes	In production of paint, varnish, pesticides and various organic solvents.	Strong narcotic, possible lung, liver and kidney damage.
Polychlorinated biphenyls (PCB)	In various electrical components; in waste oil supplies and in plastic and paper products in which PCB are used as plasticizers.	Suspected carcinogens.
Pesticides	Insect control.	Suspected carcinogens.

Source: Hollowell and Miksch (1981).

3.7.6 Moisture

Moisture, a product of everyday life, is usually not considered a pollutant. However, when it becomes excessive it may lead to building structural damage and health effects.

Measurement

Moisture in the air is often measured as relative humidity (RH). The amount of moisture air can hold depends on its temperature. Cooler air cannot hold as much water vapor as warmer air. When air holds all of the moisture that it can at a given temperature, it becomes saturated and has a relative humidity of 100%. Because warm air can hold more water vapor than can cool air, the relative humidity of the air increases as its temperature decreases. If the air cools to the point that it becomes saturated, part of the moisture is given up as condensation.

Sources

Moisture found in homes comes from a variety of sources, most of which are typical household activities. The amount of moisture produced by a typical family of four and the common sources of that moisture are shown in Table 3.26. Sources such as indoor saunas, spas, and hot tubs can dramatically increase the amount of moisture in a home.

Moisture can also enter the home from outside. As much as 20 gallons of water per day will evaporate from moist soil under a 1,400-square-foot crawl space (Ricketts 1980). How much of this moisture enters a home depends on the measures taken to block its entry. Other sources include leaks in ceilings and walls.

Health Effects

Relative humidity levels from 30 to 60% are important to maintaining a comfortable indoor environment (BPA 1984). The health effects of high moisture levels are not clearly understood or quantified. Moisture-related

TABLE 3.26. Moisture Produced by a Family of Four

Activity	Quantity Produced
Cooking (3 meals per day)	1 quart
Dishwashing (3 meals per day)	1 pint
Bathing, showering	1 pint
Clothes washing (per week)	1/2 gallon
Clothes drying indoors or with vented dryer	3 gallons
Floor mopping (per 100 square feet)	1/3 gallon
Occupants (family of 4 per day)	1-1/2 gallons
House plants	1 pint

Source: EBA 1984; Hansen 1985.

microorganisms such as spores, mold, mildew, fungi, mites, bacteria, and viruses may multiply where there is high humidity or trapped moisture (Burge 1984; Kozak et al. 1984).

Below 30% relative humidity, problems such as static electricity and nasal discomfort caused by irritated mucous membranes occur. Irritated mucous membranes also increase humans' susceptibility to infectious viruses and microorganisms. Moisture also affects health by acting as a solvent for other pollutants (Meyer 1983). For example, products made with urea-formaldehyde resins will emit higher levels of formaldehyde gas as relative humidity increases.

3.7.7 Microorganisms

Airborne microorganisms are made up of a broad collection of algae, bacteria, fungi, protozoa, mites, pollen, and viruses. Most of these come from outdoors. Indoor build-up occurs from either direct contamination or from growth on interior surfaces after contamination. All that is needed to encourage growth is a carbon base, such as cellulose, plastics, soaps, and skin, and a more or less consistent source of moisture. Relative humidity levels above 70% appear optimal for fungal spore growth (Burge 1984). Unless relative humidity is very high (above 75%), most surfaces such as paint, tile, wood, and paper do not support growth. But an area exposed to a small leak, a surface often wet from condensation, or the reservoir of an appliance may support growth. Other factors contributing to indoor microorganisms include climatic conditions, the amount of shade near a home, and organic debris levels outside of homes.

Bacteria, fungi, insects, or other biological particles usually lead to ill health only when they become airborne and are inhaled. A particularly bad situation develops when surface microorganisms grow inside ventilation systems or forced air heating/cooling systems. In these circumstances, the growth is sheltered from detection, and mechanically circulated air spreads the contaminants. There has been some concern that condensation may collect in the units of MV systems with heat recovery, allowing microorganisms to grow and then be blown into the air, although currently there is no evidence that this occurs.

Microbial flora and fauna are normal elements of the human environment. This assemblage is not only usually safe for people to be around, but also contributes essential biological functions. However, in unusual conditions, when microbial growth is unchecked and a susceptible host is present, exposure may lead to allergic reaction, asthma, or the spread of pathogen-based disease. One example was the outbreak of a mysterious respiratory disease that led to the death and ill health of several participants at an American Legion Convention in 1976. The ventilation system at the convention site was implicated in spreading the organism identified as Legionella pneumophila, which causes Legionnaires' disease.

Little research has been conducted to identify microorganisms in homes. According to Burge (1984), "The airborne bioflora is inherently complex and variable to the point that defies quantification." Burge observed that up to four sampling modalities may be necessary to accurately assess the biological particles from a single room in a "clean" house because it contains hundreds of different kinds, and technology does not exist to quantify all of them.

3.8 POLLUTANT MITIGATION TECHNIQUES

Actions to reduce indoor air pollutant levels can be grouped into two general categories: those that control pollutants at their source or block their entry, and those that remove pollutants after they enter the indoor air. Actual implementation of these techniques is dependent on the builder or consumer. To help ensure that mitigation techniques are properly chosen, installed, and operated, a third type of action should be added: information and training to support builders and consumers. These actions are summarized below. More detailed information about mitigation techniques is available in Indoor Air Quality Mitigation Technologies, Appendix C in Vol. II of the DEIS, with more recent information included in Appendix M to this Final EIS.

3.8.1 Information and Training

Disseminating information will help people choose building materials and building products, and properly install mitigation devices where needed to reduce pollutant levels. This type of general information includes booklets to homeowners, labels attached to buildings, training and certification of builders and code officials, and mass mailings of information. Information about pollutant levels in specific homes can also be made available to builders and consumers by monitoring pollutant concentrations. Monitors are available for radon, formaldehyde, nitrogen dioxide, particulates and smoke, humidity, and some organics.

Information gathered from research and demonstration projects includes the identification of geographic, geologic, and climatic factors that affect pollutant levels. An example of this is mapping the distribution of radon. When this information is available, it may be possible to estimate concentrations in given locations and take appropriate measures.

3.8.2 Source Control

Perhaps the easiest way to improve IAQ is to not pollute it in the first place by isolating pollutants, blocking pollutant entry into buildings, and modifying sources to limit emissions. Source avoidance is usually a one-time measure that entails little maintenance or operating costs.

For example, controlling sources of formaldehyde include using materials that meet HUD standards for formaldehyde emissions from particle board and plywood used in manufactured housing. Another approach is to seal sources of formaldehyde with a thick liquid-applied coating or solid sheet that forms a continuous barrier to the transport of water vapor (Matthews et al. 1983).

Source control techniques for radon include the use of monolithic slabs, ventilated crawlspaces, high-density, low-permeability concrete, exterior sealants, and subslab depressurization. Other techniques include avoiding material such as cinder block for foundations.

3.8.3 Pollutant Removal

Ventilation is one method of removing all types of pollutants. As described in section 3.2.3, ventilation can be either active (mechanical) or passive (natural). Passive ventilation includes opening windows, infiltration, manually adjusted openings, passive stacks, and wind-activated roof vents. Active ventilation includes spot ventilation and whole-house ventilation. Spot ventilation circulates air in a limited area such as over a cooking appliance, in a bathroom, or in a hobby area. Whole-house ventilation circulates air throughout a structure.

Pollutants may also be diluted somewhat by using clean air technologies such as mechanical filtration, electrostatic filtration, adsorption, absorption, and air circulation, although the efficacy of these techniques is less certain and difficult to estimate. These terms are more fully described in Indoor Air Quality Mitigation Technologies, Appendix C in Vol. II of the DEIS.

3.8.4 Mitigation Technique Effectiveness

Criteria used to evaluate mitigation methods include availability of technology, effectiveness of method, cost of installation and operation, and ease of operation. In Table 3.27, the various mitigation strategies are rated for their effectiveness at removing radon and radon progeny, formaldehyde, combustion products, and respirable particulates. Methods based on increased ventilation will reduce the concentration of all of the pollutants. The other mitigation methods have more specific targets: adsorption and absorption are effective methods for controlling formaldehyde emissions, while filtration can control respirable particulates.

In Table 3.28 we show the maturity of each mitigation method. A maturity of 1.0 means that the product or system is currently available and installed systems perform to design specifications. A maturity rating close to 0 signifies that the method is still in the design phase. Methods ranked nearest 1.0 include filtration and spot ventilation because these are well understood and widely used. Mechanical ventilation with a recuperative heat exchanger is ranked near 0.75 because AAHXs are currently available but often do not perform to design specifications. Mechanical exhaust ventilation with energy recovery is ranked near 0.5 because the technology is not widely available in the United States and there are not enough installations to know how well it performs to design specifications.

Method Sensitivity

In Table 3.29 we try to quantify the sensitivity of mitigation technologies to proper installation. Mechanical ventilation with a recuperative heat exchanger is highly dependent on proper installation, balanced air flow rates in the intake and exhaust air flows, and the proper location of air inlets and outlets. For this reason, this system is rated at 1.0, highly sensitive. Mechanical exhaust ventilation with energy recovery and regenerative process AAHX systems are less dependent on proper installation and so are ranked closer to 0, the less sensitive side of the scale.

TABLE 3.27. Effectiveness of Mitigation Strategies

Strategy	Radon and Daughters	HCHO	Combustion Products	RSP	Moisture
Source Control					
Exclusion	EFF	EFF	EFF	EFF	EFF
Source modification	EFF	EFF	EFF	EFF	EFF
Source sealing	EFF	EFF	NA	NA	NA
Subslab ventilation	EFF	NA	NA	NA	NA
Crawlspace ventilation	EFF	NA	NA	NA	NA
Air Cleaning					
Mechanical filtration	EFF	NA	EFF	EFF	NA
Electrostatic filtration	EFF	NA	EFF	EFF	NA
Adsorption	NA	EFF	NA	NA	INCON
Absorption	NA	EFF	NA	NA	EFF
Air circulation	INCON	NA	NA	INCON	INCON
Increased Ventilation					
Natural infiltration	EFF(a)	EFF	EFF	EFF	EFF
MVHX	EFF(a)	EFF	EFF	EFF	EFF
MVER	EFF(a)	EFF	EFF	EFF	EFF
RHX	EFF(a)	EFF	EFF	EFF	EFF
Spot ventilation	EFF(a)	EFF	EFF	EFF	EFF

(a) Structure depressurization caused by ventilation may increase the level of radon in residence.

EFF = effective (mitigation has potential for control of this pollutant).
INCON = inconclusive.
NA = not applicable (mitigation will not control this pollutant).
MVHX = Mechanical Ventilation with Recuperative Heat Exchanger (e.g., an air-to-air heat exchanger).
MVER = Mechanical Exhaust Ventilation with Energy Recovery.
RHX = Regenerative Process Air-to-Air Exchanger.
HCHO = Formaldehyde
RSP = respirable suspended particles

Source: Indoor Air Quality Mitigation Technologies (Table 6.1), Appendix C in Vol. II of the DEIS.

TABLE 3.28. Maturity of Mitigation Strategies

	0.0 0.5 1.0 immature------------------------------------mature
Source Control	
Exclusion	**********************************
Source modification	**********
Source sealing	**********************************
Subslab ventilation	**********************************
Crawlspace ventilation	**********************************
Air Cleaning	
Mechanical filtration	***
Electrostatic filtration	***
Adsorption	**********
Absorption	**********
Air circulation	**********************************
Increased Ventilation	
Natural infiltration	**
MVHX	**********************************
MVER	***********************
RHX	*
Spot ventilation	**
	immature------------------------------------mature 0.0 0.5 1.0

MVHX = Mechanical Ventilation with Recuperative Heat Exchanger (e.g., an air-to-air heat exchanger).

MVER = Mechanical Exhaust Ventilation with Energy Recovery.

RHX = Regenerative Process Air-to-Air Heat Exchanger.

Source: Indoor Air Quality Mitigation Technologies (Table 6.2), Appendix C in Vol. II of the DEIS.

TABLE 3.29. Sensitivity of Mitigation Strategy Performance to Installation

	0.0 0.5 1.0 insensitive-----------------------highly sensitive
Source Control	
Exclusion	***********
Source modification	***********
Source sealing	**
Subslab ventilation	**************************************
Crawlspace ventilation	**************************************
Air Cleaning	
Mechanical filtration	*******************************
Electrostatic filtration	*******************************
Adsorption	**************************************
Air circulation	***********
Increased Ventilation	
Natural infiltration	***********
MVHX	**
MVER	*******************************
RHX	*******************************
Spot ventilation	***********
	insensitive-----------------------highly sensitive 0.0 0.5 1.0

MVHX = Mechanical Ventilation with Recuperative Heat Exchanger (e.g., an air-to-air heat exchanger).
MVER = Mechanical Exhaust Ventilation with Energy Recovery.
RHX = Regenerative Process Air-to-Air Heat Exchanger.
Source: Indoor Air Quality Mitigation Technologies (Table 6.3), Appendix C in Vol. II of the DEIS.

ENVIRONMENTAL CONSEQUENCES

4.0 ENVIRONMENTAL CONSEQUENCES

In this chapter we describe and, where possible, quantify environmental changes resulting from each of the alternatives and the various pathways of the Proposed Action Alternative. The chapter is organized around the elements of the environment that are affected. First, ventilation rates and pollutant concentrations are discussed, followed by health effects, socioeconomic effects, and secondary effects. To put the New Energy-Efficient Homes Programs in the context of other BPA acquisition programs, we compare it with the acquisition of other energy resources. Finally, there is a discussion of environmental consultation, review, and permit requirements.

The analysis of environmental effects is designed to ascertain the relative, not absolute, consequences of the various alternatives so that BPA can make programmatic decisions. It is possible to rank the alternatives without quantifying how much better one pathway is than another. Even with the uncertainties inherent in the analysis, the analysis provides enough information that the lack of precision in the absolute numbers does not preclude the usefulness of the assessment for the environmental decisionmaking process.

4.1 INDOOR AIR QUALITY

To date, BPA has prevented adverse health effects in its New Homes Programs by requiring that balanced mechanical ventilation, sized to exchange air throughout a structure, be installed in tight energy-efficient homes. In homes built under BPA programs without these devices, radon and formaldehyde levels were monitored to ensure that they did not exceed 5 pCi/l and 0.1 ppm, respectively. The aim of this EIS is to assess the effects of using other mitigation techniques in addition to these. Our assessment is based on estimating the total number of potential lifetime cancers from exposure to radon and formaldehyde that may occur with each of the alternatives and each of the pathways in the Proposed Action Alternative.

4.1.1 Pollutants Analyzed

The primary environmental concern identified for the New Energy-Efficient Homes Programs is the potential effect that increased levels of indoor pollutants may have on occupants' health. The two pollutants for which health effects are estimated are radon and formaldehyde because of the range of health effects associated with them, and because risk factors have been established to calculate lifetime cancer rates.(a)

These two pollutants are also important because occupants have little control over exposure to them. Radon is a gas that cannot be sensed without monitors

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(a) While no short-term or acute health effects are linked with radon, scientists have found that formaldehyde may cause short-term effects; however, it is not yet possible to accurately quantify them on a regional basis because of the variability in human response.

and is emitted into Northwest homes almost entirely from soil. Although consumers can control formaldehyde levels somewhat by their choice of furnishings after a house is built, they usually have little control over formaldehyde-emitting materials used to build the house.

In its Final EIS on the Expanded Residential Weatherization Program BPA treated benzo[a]pyrene (BaP) as a carcinogen with quantifiable impacts (BPA 1984); that analysis assumed that the potential carcinogenicity of complex mixtures such as wood and tobacco smoke could be estimated on the basis of BaP content. Moreover, the carcinogenicity of BaP in these mixtures was assumed to be similar to BaP's carcinogenicity in pure form. As discussed in Section 3.7.3, these assumptions are no longer valid. Based on new data now available, we now recognize that there is not enough information to quantify the health effects of wood smoke and tobacco smoke.

We also found that there is not enough information to quantify the long-term health effects of respirable particulates, combustion gases, moisture, microorganisms, or household chemicals. This does not imply that these pollutants do not affect human health. There is just not enough information to predict how different people will respond to low levels of these pollutants over long periods of time. There is also considerable uncertainty concerning the levels of some of these pollutants found in homes. And finally, there is uncertainty about how these pollutants react and interact in indoor air to form different compounds that can result in different health effects. Thus, while there is qualitative evidence of risk, we cannot formulate policy or management strategies based on that body of evidence-- and, the EIS is a planning document and the basis for policy decisions.

The health effects of indoor pollutants are discussed in more detail in the DEIS, Vol. II, Appendix B. There are also two new appendixes to this Final EIS, one on man-made manufactured fibers such as fiber glass insulation (Appendix J) and one on environmental tobacco smoke (Appendix K).

4.1.2 Methodology

The basic model used to estimate lifetime cancers from changes in IAQ is as follows:

$$\left(\begin{array}{l}\text{Pollutant}\\ \text{risk factor}\end{array}\right) \times \left(\begin{array}{l}\text{Number of people}\\ \text{living in homes}\end{array}\right) \times \left(\begin{array}{l}\text{Forecast number}\\ \text{of homes}\end{array}\right) \times \left(\begin{array}{l}\text{Measured or scaled}\\ \text{pollutant}\\ \text{concentration}\end{array}\right)$$

$$= \begin{array}{l}\text{Number of potential incidents of lifetime cancers}\\ \text{in a given house type at a given pollutant concentration.}\end{array}$$

Individual risk factors, discussed in Sections 3.7.1 and 3.7.2, were applied to several subsets of the affected population, and the results summed to determine the total regional impact. The subsets were distinguished by housing type, pollutant type, and pollutant level (radon only), and the model applied to the baseline. The variables used in the model are summarized in this section.

Each value used in the model has a margin of uncertainty associated with it, the cumulative effect of which may contribute to a reduction in the accuracy of the reported results. For a discussion of uncertainty in reported data, see Appendix L. Additional information on the model is in Appendix C to this Final EIS (Vol. II), as well as in the DEIS, Vol. II, Appendix B.

Pollutant Risk Factor

Based on a review of the literature on the health effects of radon and formaldehyde, the following individual risk factors are most applicable to the residential environment:

- radon risk factor = 0.0021 estimated lifetime cancers per 1 pCi/l of radon (or 2.1 lifetime cancers per 100 people)
- formaldehyde risk factor = 0.00109 estimated lifetime nasal cancers per 1 ppm of formaldehyde (or 1.09 lifetime cancers per 100 people).

The risk of undertaking activities such as driving an automobile is compared with that of exposure to radon in Section 4.2.3 and in Appendix D. More information on pollutant risk factors is available in Chapter 3.

Population Density

The number of occupants per residence is constant across each of the alternatives and was shown in Table 3.12.

Housing Forecasts

We used BPA's 1986 medium case forecast (the DEIS used the 1985 forecast) for the construction of new electrically heated homes in the region. Projections for the three housing types under consideration were presented in Tables 3.9 through 3.11 for the Baseline and No Additional Action Alternative.

Pollutant Concentrations

We used measurements of radon and formaldehyde concentrations taken as part of the RSDP. The health effects analysis is based on data taken in houses built to 1983 practice; that data provided the best representation to estimate the effect of house tightening on pollutant concentrations, which is what we are trying to model. Using these data, along with prototypical volumes of single-family, multifamily, and manufactured homes, we were able to estimate, or scale, pollutant concentrations to match different ventilation rates and housing types. Formaldehyde concentrations for manufactured and single-family homes were based on measured data and are considered fairly reliable; however, the concentrations estimated for multifamily housing were extrapolated from the single-family measurements, and therefore contain a higher level of uncertainty.

Ventilation rates and structure volume are important determinants in establishing pollutant levels in homes. Given a constant volume and source of pollution for individual housing types, pollutant levels will decrease as ventilation rates increase. Based on this steady-state model, the relationship between ventilation and pollutant levels is such that, for every doubling of ventilation, pollutant levels decrease by half. And for every halving of ventilation, pollutant levels double. Assuming this inverse relationship, and using measured pollutant levels and ventilation rates as starting points, we are able to estimate, or scale, pollutant concentrations at different ventilation rates. This relationship is expressed by the following equation:

$$C = \frac{S}{VI}$$

where C = pollutant concentration
S = source emission
V = volume
I = effective ventilation rate.

As noted in Section 3.7.2, the beneficial effects of ventilating formaldehyde may be offset somewhat by an increase in emissions from pollutant sources. Thus, the model may overpredict the reduction in formaldehyde levels due to ventilation. However, ventilation does effectively mitigate the pollutant, and developing a separate, more complex model for formaldehyde would be an expensive and complex addition to the analysis; the cost of this would not be commensurate with the value of the information gained.

The following dwelling volumes are assumed in our calculation of pollutant levels and remain constant across climate zones and alternatives:

° single-family:	11,200 cubic feet
° multifamily:	6,720 cubic feet per unit
° manufactured housing:	9,360 cubic feet.

Ventilation Rates for the Alternatives

The most important variable in our analysis of the New Energy-Efficient Homes Programs is the difference in ventilation rates between 1983 practice and new energy-efficient homes. We estimated this difference and its impact on indoor pollutant levels to estimate health effects that may result from the programs. First it was necessary to establish the starting point, or baseline conditions, to which we compare energy-efficient homes.

Bonneville estimated both average and effective ventilation rates in homes built to 1983 practice and energy-efficient homes for each of the alternatives. To estimate both the average and effective ventilation rates, BPA used the air infiltration model developed by LBL to compute air change rates and equivalent pollutant concentrations (i.e., the inverse of the air change rate) on an hourly basis. Both quantities were then averaged, and the inverse of average pollutant concentrations was taken as the effective air change rate. The effective ventilation rate better represents the amount of time an occupant is exposed to a given level of pollutant concentration. The lower the exposure-weighted ACH, the more exposure to pollutants. Since the health effects analysis relies on the effective ventilation rate, this rate is the value cited below in the summary of alternatives. The assumptions and methodology for these estimates are explained in Appendix A.

- Baseline - In the RSDP, BPA studied the ventilation rates of some 450 new homes built to 1983 practice. Results from the studies indicated so much uncertainty in determining the ventilation rate for the Baseline, that BPA created a range based on these results that best represents the bounds of ventilation rates in baseline homes, with an upper bound of 0.45 ACH and a lower bound of 0.35 ACH across all three climate zones. We assume that no energy-efficient homes are built in the Baseline.

- No Additional Action Alternative - The No Additional Action Alternative consists of programs which will produce tighter, energy-efficient houses. However, these programs have components designed specifically to maintain ventilation rates prevailing in 1983 building practice. This alternative is thus analyzed with the same effective ventilation rates found in the Baseline.

- Proposed Action Alternative - To assess the effectiveness of various techniques at maintaining the quality of indoor air, this alternative is subdivided into a series of pathways. The most important variable in the assessment of the pathways is the effective ventilation rates achieved in energy-efficient homes. Most of the pathways rely on some form of mechanical ventilation to reduce pollutant levels, although two have no such requirement. We assess the pathways for their impact on pollutant concentrations and resulting health effects based on both the upper and lower bounds of each pathway's effective ventilation rate. In our model, the Baseline has the same pollutant concentration regardless of the ventilation rate. Since everything else is held constant (e.g., dwelling type, housing forecast, climate zone), it is possible to assess the effect of changing the air exchange rate by examining the ratio of the pathway's air exchange rates to the Baseline's air exchange rates.

The pathways are distinguished by their level of infiltration, the type of MV system, and the length of time that MV system operates (Figure 2.1). For example, one pathway has a continuous air barrier and MVHR system which operates 8 hr/day (to account for controls or occupant behavior that may limit the operating time). Hence, the overall ventilation rate in this pathway is a combination of natural and mechanical ventilation. These pathway components yield the average ventilation rates, which are then used to calculate the effective ventilation rate (see Chapter 2 and Appendix A).

As described in Chapter 2, some houses in Pathway 6 may be retrofit with ports if a diagnostic blower door test indicates the need. However, because we cannot predict the number of houses that might need ports, our health effects analysis adopts the assumption that no houses are retrofit with ports. Thus, the ventilation rate used to analyze the pathway is the same as originally calculated. This has the effect of overestimating the cancer rate for the pathway, because it is likely that some number of houses will install ports. For those houses receiving ports, the ventilation rate would increase to that estimated for Pathway 5, with a corresponding decrease in the incidence of cancer. For the planning purposes of this document, we have elected to overestimate rather than underestimate the adverse health effects. The ventilation rates achieved under each of the pathways are shown in Table 4.1, which summarizes the basic elements of the pathways. For more information on the pathways, see Chapter 2.

Estimated Pollutant Concentrations

We determined indoor radon and formaldehyde concentrations for each housing type in each climate zone for the Baseline (BPA 1986g). Our method, based on the fairly standard approach that reductions in air exchange rates result in increased indoor concentrations of the pollutant in rough proportionality to the source term, is summarized below.

- For radon we calculated median concentrations for homes with indoor concentrations greater than 5 pCi/l (high level) and for homes with levels less than or equal to 5 pCi/l (low level). Because the data were so closely spaced, formaldehyde concentrations were not divided into high and low concentrations. These are arbitrary distinctions but are useful in differentiating between homes with lower risk and those at greatest risk. They also better control for outliers in the data set, which are more prevalent with radon. The 5 pCi/l level for radon is based on Bonneville's action level for its weatherization program (BPA 1984). The data used to calculate radon and formaldehyde concentrations are presented in Appendix C. The proportion of homes with high concentrations to homes with low concentrations is then taken into account in estimating the total number of lifetime cancers. The percentages of structures with high and low concentrations for each climate zone are shown in Table 4.2. Note that only a small percentage of homes in the region exceed 5 pCi/l, and of those, 98% are located in climate zones 2 and 3.

- For radon, the median concentrations for both energy-efficient homes and those built to 1983 practice in each of the climate zones are based on measured data taken from single-family control homes in the RSDP. The baseline concentrations are based only on single-family control homes; these are simply scaled to estimate concentrations for multifamily and manufactured homes. Table 4.3 shows the concentration for the Baseline, for all three housing types in all three climate zones. For formaldehyde, we calculated mean concentrations based on measured data taken from both single-family and manufactured homes. Single-family concentrations were scaled to derive estimates for multifamily homes.

- We then scaled the pollutant concentrations to match the varying volumes of the different housing prototypes and the varying effective ventilation rates of the pathways as developed in Appendix A, and given in Table 4.1.

TABLE 4.1. Summary of Pathways' Effective Ventilation Rates

Pathway	Infiltration Control(a)	MV System	MV Operation(b)	Range of Effective Ventilation Rates			
					Single-Family	Multi-Family	Manufactured
1	Standard	None	NA	Upper	.32	.19	.31
				Lower	.26	.15	.29
2	Standard	MVHR(c)	Continuous	Upper	.52	.45	.53
				Lower	.45	.40	.50
3	Standard	MVHR(c)	Intermittent	Upper	.37	.24	.36
				Lower	.31	.20	.34
4	Standard	Exhaust	Continuous	Upper	.45	.47	.46
				Lower	.38	.42	.43
5	Standard	Exhaust	Intermittent	Upper	.38	.29	.38
				Lower	.31	.24	.35
6	Standard	Exhaust	Intermittent	Upper	.35	.24	.35
				Lower	.29	.19	.32
7	Advanced	None	NA	Upper	.17	.12	.16
				Lower	.14	.11	.13
8	Advanced	MVHR(c)	Continuous	Upper	.43	.37	.42
				Lower	.40	.36	.39
9	Advanced	MVHR(c)	Intermittent	Upper	.21	.15	.20
				Lower	.18	.14	.17
10	Advanced	Exhaust	Continuous	Upper	.34	.41	.34
				Lower	.30	.40	.30
11	Advanced	Exhaust	Intermittent	Upper	.24	.21	.23
				Lower	.20	.19	.19

(a) Standard = Minimum MCS construction for air leakage control; advanced = continuous air barrier.
(b) Continuous = 24 hours/day; intermittent = 8 hours/day.
(c) MVHR = Mechanical ventilation system with heat recovery, or air-to-air heat exchanger.

TABLE 4.2. Percentages of Single-Family and Multifamily Homes With High and Low Pollutant Concentrations by Climate Zone

	Single-Family Homes		Multifamily Homes	
Climate Zone	Low Radon Concentration	High Radon Concentration	Low Radon Concentration	High Radon Concentration
1	98%	2%	100%	0
2	78%	22%	100%	0
3	75%	25%	100%	0

TABLE 4.3. Radon and Formaldehyde Concentrations in Baseline Homes

	Rn Concentrations		Cancer Rate From Radon[b]	Average HCHO Concentrations, ppm
	≤5pCi/l	>5pCi/l		
Climate Zone 1				
Single-family	0.41(a)	10.52(a)	118	.09
Multifamily	1.49	--	313	.11
Manufactured Homes(c)	0.49	12.59	141	.11
Climate Zone 2				
Single-family	1.51(a)	9.56(a)	692	.09
Multifamily	1.35	--	284	.11
Manufactured Homes(c)	1.81	11.44	829	.11
Climate Zone 3				
Single-family	2.23(a)	9.76(a)	857	.09
Multifamily	1.35	--	283	.11
Manufactured Homes(c)	2.67	11.68	1,026	.11

(a) Median concentrations
(b) Total lifetime lung cancers per 100,000 persons
(c) Radon concentrations are medians scaled from concentrations in single-family homes; formaldehyde concentrations are means scaled from single-family homes.

To assess radon mitigation techniques included in the radon package for use in homes with levels above 5 pCi/l, we assumed that the mitigation will reduce concentrations by 70% in those homes where mitigation measures are activated. This assumption is based on monitoring data taken from 15 homes tested for radon reduction techniques (Turk et al. 1986; Thor 1987). However, the total regional effect of the radon package is very slight because it is assumed to affect a very small percentage of homes as shown in Table 4.4. The mitigation measures included in the radon package are described in Appendix H.

4.2 ESTIMATED HEALTH EFFECTS

Using the model presented in Section 4.1, we estimated the number of potential lifetime cancers resulting from exposure to radon and formaldehyde from each alternative and each of the pathways of the Proposed Action Alternative based on each ventilation rate. For example, for each pathway, we calculated the lifetime cancer rate for the percentage of both 1983 practice and energy-efficient homes, then aggregated them to give the total cancer rate for the pathway. We can then directly compare the effect of the pathway to that of the Baseline. These estimates are presented in Section 4.2.1. In Section 4.2.3 we compare the radon findings with risks of other activities such as driving a car and smoking tobacco. This comparison assumes that the incidence of lung cancer results in death, although this assumption is not universally accepted.

Risk assessments are an important component in the decisionmaking process. However, there are sources of uncertainty and error in risk assessments, and it is important to understand the limitations on the quantitative results. As a result of the uncertainty inherent in the risk assessment, the calculated risks should be regarded as maximum estimates since our errors will be overpredictions. It is also important to understand that the numbers given in the following tables estimate relative changes in risk and do not predict what will actually happen. The analysis is focused on evaluating not the certain occurrence of cancer for a specific individual but rather the increase or

TABLE 4.4. Radon Package Adoption Assumptions

Radon Range, pCi/l	% of Houses[(a)] in the Range	x	% of People[(b)] Taking Action	=	% Reduction[(c)]
0- 5	90		0		0
5-10	5		10		.5
10-20	4		30		1.2
20+	1		75		.75
Total % of houses taking action					2.45
Assumed fractional reduction of Rn					x .7
Total regional reduction					1.7%

(a) Based on RDSP data for 1983 practice homes, but for illustrative purposes, we assume the listed percentages.

(b) Best judgement based on BPA's experience with the Weatherization Program.

(c) Assuming the percentages in Column 2.

decrease in the probability of lifetime lung disease for each individual member of a larger population at risk (Dunford et al. 1986). In view of the many uncertainties associated with estimating cancer rates, the differences between the estimates of lifetime cancers for the various alternatives and pathways are more important than the numbers themselves.

4.2.1 Lifetime Cancer Rates

It is difficult to directly compare the number of lifetime cancers estimated for each alternative because the size of the affected population changes from alternative to alternative and is a key variable in estimating the number of lifetime cancers. The difference in population size is demonstrated by comparing the total affected population of the Baseline, 1,797,281 persons, and that of the No Additional Action Alternative, 1,305,409 persons. The larger population of the Baseline leads to a larger number of lifetime cancers even though we assume in the Baseline that there are no energy-efficient houses.

The differences in population size among alternatives is taken into account when we estimate the potential lifetime cancer rate of a given exposed population of 100,000 persons. Lifetime cancers per 100,000 persons is the number of cancers predicted to occur in a population of 100,000 persons over a given number of years of exposure. This normalized potential cancer rate is shown for each of the alternatives and each pathway of the Proposed Action Alternative in Tables 4.5 through 4.10.

The cancer rate does not change from the Baseline to the No Additional Action Alternative because the programs that comprise that alternative have been designed to result in IAQ and health effects that are equivalent to, or better than, those resulting from the Baseline.

The most noticeable pattern in the tables of health effects is the one we would expect: as ventilation rates drop, the cancer rate increases. For illustration, look at the lower bound values in Table 4.5, where the cancer rate from radon in single-family homes ranges from 277 cancers per 100,000 associated with .45 ACH to 601 cancers per 100,000 when the ventilation rate is decreased to .14 ACH. This pattern also holds for the other two housing types.

The other noticeable pattern seen in Table 4.5 is how little difference there is among the pathways. With the exception of Pathways 7, 9, and 11, there is little difference from one pathway to the next. Nor are their health effects dramatically different from those resulting from the Baseline (335); in effect, they fall within the range of the Baseline. The conclusion would seem to be that a large change in the total effective ventilation rate is required to effect a real change in the cancer rate. For the most part, the changes in the ventilation rates that occur due to the proposed pathways are too slight to result in health effects that are greatly different from the Baseline. Only when the air exchange rate is reduced by nearly 43% (from 0.35 ACH to 0.20 ACH in Pathway 11) do changes in health effects become apparent.

The decreased number of cancers under Pathway 8 (upper bound), even though it has a lower ventilation rate, is explained by the required implementation of

TABLE 4.5. Health Effects from Radon in Single-Family Homes

Alternatives		Cancers (Upper Bound) 1983 Practice	Cancers (Upper Bound) Energy-Efficient	Cancers (Upper Bound) Pathway Total	Cancers (Lower Bound) 1983 Practice	Cancers (Lower Bound) Energy-Efficient	Cancers (Lower Bound) Pathway Total
Baseline							
	No. of Cancers	6019			6019		
	Rate/100,000	335			335		
No Additional Action							
	No. of Cancers	6019			6019		
	Rate/100,000	335			335		
Proposed Action Pathways							
1	No. of Cancers	1677	3496	5173	1677	3346	5023
	Rate/100,000	335	434	396	335	416	385
2	No. of Cancers	1677	2151	3828	1677	1933	3611
	Rate/100,000	335	267	293	335	240	277
3	No. of Cancers	1677	3023	4700	1677	2807	4484
	Rate/100,000	335	376	360	335	349	343
4	No. of Cancers	16772	2486	4163	1677	2290	3967
	Rate/100,000	335	309	319	335	285	304
5	No. of Cancers	1677	2944	4621	1677	2807	4484
	Rate/100,000	335	366	354	335	349	343
6	No. of Cancers	1677	3196	4873	1677	3000	4677
	Rate/100,000	335	397	373	335	373	358
7	No. of Cancers	1677	6534	8211	1677	6171	7848
	Rate/100,000	335	812	629	335	767	601
8	No. of Cancers	1677	2601	4279	1677	2175	3852
	Rate/100,000	335	323	328	335	270	295
9	No. of Cancers	1677	5327	7004	1677	4834	6511
	Rate/100,000	335	662	537	335	601	499
10	No. of Cancers	1677	3290	4967	1677	2900	4577
	Rate/100,000	335	409	381	335	360	351
11	No. of Cancers	1677	4661	6338	1677	4350	6027
	Rate/100,000	335	579	486	335	541	462

TABLE 4.6. Health Effects from Radon in Multifamily Homes

Alternatives		Cancers (Upper Bound)			Cancers (Lower Bound)		
		1983 Practice	Energy-Efficient	Pathway Total	1983 Practice	Energy-Efficient	Pathway Total
Baseline							
	No. of Cancers	1752			1752		
	Rate/100,000	306			306		
No Additional Action							
	No. of Cancers	1752			1752		
	Rate/100,000	306			306		
Proposed Action Pathways							
1	No. of Cancers	623	1760	2383	623	1486	2110
	Rate/100,000	306	482	419	306	407	371
2	No. of Cancers	623	743	1366	623	557	1181
	Rate/100,000	306	204	240	306	153	208
3	No. of Cancers	623	1393	2017	623	1115	1738
	Rate/100,000	306	382	355	306	306	306
4	No. of Cancers	623	712	1335	623	531	1154
	Rate/100,000	306	195	235	306	145	203
5	No. of Cancers	623	1153	1776	623	929	1552
	Rate/100,000	306	316	312	306	255	273
6	No. of Cancers	623	1393	2017	623	1173	1797
	Rate/100,000	306	382	355	306	322	316
7	No. of Cancers	623	2787	3410	623	2027	2650
	Rate/100,000	306	764	599	306	556	466
8	No. of Cancers	623	904	1527	623	619	1243
	Rate/100,000	306	248	268	306	170	218
9	No. of Cancers	623	2229	2853	623	1592	2216
	Rate/100,000	306	611	502	306	436	390
10	No. of Cancers	623	816	1439	623	557	1181
	Rate/100,000	306	224	253	306	153	208
11	No. of Cancers	623	1592	2216	623	1173	1797
	Rate/100,000	306	436	390	306	322	316

TABLE 4.7. Health Effects from Radon in Manufactured Homes

Alternatives		Cancers (Upper Bound)			Cancers (Lower Bound)		
		1983 Practice	Energy-Efficient	Pathway Total	1983 Practice	Energy-Efficient	Pathway Total
Baseline							
	No. of Cancers	2356			2356		
	Rate/100,000	413			413		
No Additional Action							
	No. of Cancers	2356			2356		
	Rate/100,000	413			413		
Proposed Action Pathways							
1	No. of Cancers	1799	666	2465	1799	712	2510
	Rate/100,000	413	493	432	413	527	440
2	No. of Cancers	1799	390	2188	1799	413	2211
	Rate/100,000	413	289	384	413	306	388
3	No. of Cancers	1799	574	2372	1799	607	2406
	Rate/100,000	413	425	416	413	450	422
4	No. of Cancers	1799	449	2247	1799	480	2279
	Rate/100,000	413	333	394	413	356	399
5	No. of Cancers	1799	543	2342	1799	590	2388
	Rate/100,000	413	403	411	413	437	419
6	No. of Cancers	1799	590	2388	1799	645	2444
	Rate/100,000	413	437	419	413	478	428
7	No. of Cancers	1799	1279	3077	1799	1501	3299
	Rate/100,000	413	947	539	413	1112	578
8	No. of Cancers	1799	492	2290	1799	529	2328
	Rate/100,000	413	364	401	413	392	408
9	No. of Cancers	1799	1023	2822	1799	1204	3002
	Rate/100,000	413	758	495	413	892	526
10	No. of Cancers	1799	607	2406	1799	688	2487
	Rate/100,000	413	450	422	413	510	436
11	No. of Cancers	1799	898	2696	1799	1077	2875
	Rate/100,000	413	665	473	413	798	504

TABLE 4.8. Health Effects from Formaldehyde in Single-Family Homes

		Cancers (Upper Bound)			Cancers (Lower Bound)		
Alternatives		1983 Practice	Energy-Efficient	Pathway Total	1983 Practice	Energy-Efficient	Pathway Total
Baseline							
	No. of Cancers	176			176		
	Rate/100,000	10			10		
No Additional Action							
	No. of Cancers	176			176		
	Rate/100,000	10			10		
Proposed Action Pathways							
1	No. of Cancers	49	111	160	49	106	155
	Rate/100,000	10	14	12	10	13	12
2	No. of Cancers	49	68	117	49	61	111
	Rate/100,000	10	8	9	10	8	8
3	No. of Cancers	49	96	145	49	89	138
	Rate/100,000	10	12	11	10	11	11
4	No. of Cancers	49	79	128	49	73	122
	Rate/100,000	10	10	10	10	9	9
5	No. of Cancers	49	93	143	49	89	138
	Rate/100,000	10	12	11	10	11	11
6	No. of Cancers	49	101	151	49	95	144
	Rate/100,000	10	13	12	10	12	11
7	No. of Cancers	49	209	258	49	197	246
	Rate/100,000	10	26	20	10	25	19
8	No. of Cancers	49	83	132	49	69	118
	Rate/100,000	10	10	10	10	9	9
9	No. of Cancers	49	169	218	49	153	203
	Rate/100,000	10	21	17	10	19	16
10	No. of Cancers	49	104	154	49	92	141
	Rate/100,000	10	13	12	10	11	11
11	No. of Cancers	49	148	197	49	138	187
	Rate/100,000	10	18	15	10	17	14

TABLE 4.9. Health Effects from Formaldehyde in Multifamily Homes

Alternatives		Cancers (Upper Bound) 1983 Practice	Cancers (Upper Bound) Energy-Efficient	Cancers (Upper Bound) Pathway Total	Cancers (Lower Bound) 1983 Practice	Cancers (Lower Bound) Energy-Efficient	Cancers (Lower Bound) Pathway Total
Baseline							
	No. of Cancers	69			69		
	Rate/100,000	12			12		
No Additional Action							
	No. of Cancers	69			69		
	Rate/100,000	12			12		
Proposed Action Pathways							
1	No. of Cancers	24	69	94	24	58	83
	Rate/100,000	12	19	16	12	16	15
2	No. of Cancers	24	29	54	24	22	46
	Rate/100,000	12	8	9	12	6	8
3	No. of Cancers	24	55	79	24	44	68
	Rate/100,000	12	15	14	12	12	12
4	No. of Cancers	24	28	52	24	21	45
	Rate/100,000	12	8	9	12	6	8
5	No. of Cancers	24	45	70	24	36	61
	Rate/100,000	12	12	12	12	10	11
6	No. of Cancers	24	55	79	24	43	71
	Rate/100,000	12	15	14	12	13	12
7	No. of Cancers	24	109	134	24	80	104
	Rate/100,000	12	30	24	12	22	18
8	No. of Cancers	24	35	60	24	24	49
	Rate/100,000	12	10	11	12	7	9
9	No. of Cancers	24	87	112	24	62	87
	Rate/100,000	12	24	20	12	17	15
10	No. of Cancers	24	32	56	24	22	46
	Rate/100,000	12	9	10	12	6	8
11	No. of Cancers	24	62	87	24	46	71
	Rate/100,000	12	17	15	12	13	12

TABLE 4.10. Health Effects From Formaldehyde in Manufactured Homes

Alternatives		Cancers (Upper Bound) 1983 Practice	Energy-Efficient	Pathway Total	Cancers (Lower Bound) 1983 Practice	Energy-Efficient	Pathway Total
Baseline							
	No. of Cancers	67			67		
	Rate/100,000	12			12		
No Additional Action							
	No. of Cancers	67			67		
	Rate/100,000	12			12		
Proposed Action Pathways							
1	No. of Cancers	51	21	72	51	22	74
	Rate/100,000	12	16	13	12	17	13
2	No. of Cancers	51	12	63	51	13	64
	Rate/100,000	12	9	11	12	10	11
3	No. of Cancers	51	18	69	51	19	70
	Rate/100,000	12	13	12	12	14	12
4	No. of Cancers	51	14	65	51	15	66
	Rate/100,000	12	10	11	12	11	12
5	No. of Cancers	51	17	68	51	19	70
	Rate/100,000	12	13	12	12	14	12
6	No. of Cancers	51	19	70	51	20	71
	Rate/100,000	12	14	12	12	15	13
7	No. of Cancers	51	41	92	51	50	101
	Rate/100,000	12	30	16	12	37	18
8	No. of Cancers	51	15	67	51	17	68
	Rate/100,000	12	11	12	12	12	12
9	No. of Cancers	51	32	84	51	38	89
	Rate/100,000	12	24	15	12	28	16
10	No. of Cancers	51	19	70	51	22	73
	Rate/100,000	12	14	12	12	16	13
11	No. of Cancers	51	28	79	51	34	85
	Rate/100,000	12	21	14	12	25	15

the radon package for houses in the Proposed Action Alternative. While homes in the Baseline receive no mitigation, some of the homes with radon levels exceeding 5 pCi/l are assumed to have radon concentrations cut by 70% by the radon package in the Proposed Action. So, while the ventilation rates are similar, reduced pollutant source strengths result in lower concentrations and fewer estimated cancers.

The effect of the radon package is practically imperceptible at this level of aggregation, and is most easily discerned in Pathways 4 and 8 for the upper bound values. Pathway 4 has the same effective ventilation rate as the Baseline, yet Pathway 4 results in a lower cancer rate than the Baseline. And, not only does Pathway 4 have a lower cancer rate than the Baseline, but the difference between the two is greater than what would be expected based on the numerical relationships between cancer rate and ventilation rate that prevail in the other pathways. Pathway 8's ventilation rate is 0.02 ACH less than the Baseline (0.43 versus 0.45 ACH); yet it also results in a lower cancer rate. Because everything else is held nearly constant at these very small differences (0 to 0.02) in ventilation rates, the effect of the radon package is the dominant difference and thus becomes visible; when other variables are changing, the radon package is no longer the dominant effect and is less perceptible.

As ventilation rates drop further in the energy-efficient homes of Pathways 7, 9 and 11, the lifetime cancer rate is greater than that of the Baseline. The cancer rate increases in these pathways, despite the radon package, because the radon package applies only to a small fraction of homes in the pathways--those that exceed 5 pCi/l and where occupants choose to take mitigative action. In the much larger fraction of homes, although reduced ventilation leads to higher radon concentrations, they are still below the action level of 5 pCi/l. The following example will help explain this situation:

- Using Pathway 6 as the example, the difference in (upper bound) ventilation rates between the 1983 practice homes of the Baseline (0.45 ACH) and the energy-efficient homes of Pathway 6 (0.35 ACH) is about 0.1 ACH, four-fifths (4/5) the ventilation rate of baseline homes.

- In our analysis we assume that, in homes where volume and pollutant source strength remain constant, the pollutant concentration is inversely proportional to ventilation rates.

- If the ventilation rate in an energy-efficient home is four-fifths that of a current practice home, then pollutant concentrations will be 25% greater (the inverse of 4/5 is 5/4 or 1.25). If ventilation is divided by two--a 50% decrease--then pollutant concentrations are doubled.

- In our calculation, if a home with a ventilation rate of 0.45 ACH has a radon concentration of 1 pCi/l, the radon level will increase to 1.25 pCi/l when ventilation decreases to 0.35 ACH.

- Using this same reasoning, a home with a ventilation rate of 0.45 ACH must have a radon level greater than 4.0 pCi/l before a reduction in ventilation to 0.35 ACH will result in radon levels exceeding 5 pCi/l (4.0 pCi/l x 1.25 = 5.0 pCi/l).

- Data from the monitoring of 27,000 homes participating in Bonneville's Residential Weatherization Program demonstrate that only about 6.4% of the homes in the Northwest exceed 3 pCi/l (BPA 1988b).

- Many people with lower radon concentrations receive a small increase in risk while the few with the highest concentrations have their risk reduced through the radon package. These small increases in risk to many people add up to push the lifetime cancer rate above that of the baseline although the radon package reduces the risk to the individual where it is greatest.

This situation also applies to Pathway 7, but the ventilation rates in this pathway are much lower. The ventilation rate in energy-efficient homes is less than 0.2 ACH, leading to the greatest estimated lifetime cancer rates of any of the alternatives and pathways.

The example of Pathway 6 also presents another important consideration. In this pathway some number of households would install ports (following a blower door test) which, when combined with all the homes in the pathway, would result in a higher ventilation rate and thus lower cancer rate. But, as explained earlier, we do not model that assumption in the EIS.

4.2.2 Short-Term Health Effects

Short-term or acute health effects have not been identified for radon. However, as discussed in Section 3.8, formaldehyde is an irritant of the eyes, skin, and respiratory tract. Within the range of 0.1 to 0.3 ppm, most people experience irritation to the eyes, nose, and throat. Between 10 and 20 ppm, symptoms are severe and breathing becomes difficult. Sensitive people may experience symptoms at lower concentrations.

Formaldehyde levels measured for energy-efficient homes range from 0.021 to 0.376 ppm, with a mean level of 0.09 ppm. This mean is very close to the ASHRAE-recommended level of 0.1 ppm, but well below the target level of 0.4 ppm set by HUD for manufactured housing. At the levels measured we expect that some sensitive people may experience difficulty, but it is not now possible to anticipate specific adverse health effects.

4.2.3 Comparison of Risk

All societies and individuals recognize exposure to personal risk as a normal part of life. Table 4.11 sets the risks of contracting cancer from exposure to radon against other forms of risk from voluntary activities. In Table 4.11, the risks calculated for different alternatives are compared with other activities resulting in a common degree of risk, i.e., one incident in a population of 100,000 persons over some specified period of time or length of

TABLE 4.11. Voluntary Activities that Carry a Risk of One Incident for Each 100,000 Persons Participating

Activity	Incidence
Breathing 0.0048 pCi/L radon for life	Lung cancer
Traveling 7000 miles by air	Accidental death
Traveling 600 miles by automobile	Accidental death
Living for 2 years in Denver	Cancer from cosmic rays
Working for 15 weeks in a typical factory	Accidental death
Working for 30 hours in a coal mine	Accidental death
Smoking from 10 to 30 cigarettes	Cancer, heart-lung disease
Rock climbing for 15 minutes	Accidental death

Sources: BPA 1984; Upton 1982.

activity. More information on accepting and calculating risk is presented in Appendix D.

4.3 ECONOMIC AND SOCIAL EFFECTS

Economic effects are defined as changes in key economic variables such as price, cost, income, and employment. We analyzed social effects by determining changes in community resources, social organizations, and well being. Much of the information for this section comes from Economic and Social Effects of Model Conservation Standards, Appendix D in Vol. II of the DEIS.

4.3.1 Energy Savings

We estimated the energy savings of each of the alternatives and the pathways of the Proposed Action Alternative using the methodology documented in Appendix A, Vol. II of the DEIS. Changes made since the DEIS are documented in Appendix G to this Final EIS. No energy savings are listed for the Baseline because we assume that no energy-efficient homes are built. Energy savings were calculated using the average ventilation rates developed by BPA (in Appendix A) and listed in Appendix G, Table G.1.

The first step in estimating energy savings was to model energy use in energy-efficient homes and in homes built to 1983 practice. Then savings were calculated by subtracting the projected energy use of a prototypical energy-efficient home from that of a 1983 practice home. Resulting estimated annual energy savings of prototypical dwellings are given in Table 3.7.

Using these energy saving figures, we estimated energy savings on a regional basis for each of the alternatives. We calculated regional savings as the difference between: (1) energy usage of all new electrically space-heated homes assumed to be built to 1983 practice and (2) energy usage of all the homes assumed to be built in accordance with each of the alternatives and pathways. The electrically heated homes of the alternatives include a weighted mixture (based on BPA's 1986 medium forecast) of both 1983 practice and energy-efficient homes. Another way of expressing the calculation is as follows:

RS = ESB-ESA

where:

RS = Regional energy savings for the given alternative
ESB = Energy use assuming all homes are built to 1983 practice
ESA = Energy use of the given alternative or pathway

This calculation takes into account the decreased energy requirements of energy-efficient homes as well as accounting for the number of electrically space-heated homes projected for each alternative.

Energy savings for the No Additional Action Alternative is based on the same ventilation rate as in the Baseline, but in this alternative the air exchange rate is achieved by the technologies found in Pathways 5 and 8 (the current options for MCS). To get from the ventilation rate to energy consumption, we need to add the number of homes. Thus we made an assumption about the percentage of the forecast to be in each pathway: in climate zone 1, 100% of homes are in Pathway 5; in climate zone 3, 100% are in Pathway 8; and in Climate Zone 2, 65% are in Pathway 5, and 35% Pathway 8. Table 4.12 gives the regional energy savings to be derived from the No Additional Action Alternative.

TABLE 4.12. Potential Energy Savings of the No Additional Action Alternative, 1986-2006

Dwelling Type	Average Megawatts Upper Bound	Lower Bound
Single-Family	104	97
Multifamily	28	21
Manufactured Homes	39	37
Total	171	155

The pathways of the Proposed Action Alternative were handled differently. Each pathway was evaluated as if all energy-efficient homes followed that pathway. More information about this technique is presented in Appendix G. The energy savings estimated for each pathway are shown in Table 4.13 for single-family, multifamily, and manufactured homes.

It is fairly clear from Table 4.13 that the continuous air barrier is the biggest factor for energy savings. Pathway 3 is the only pathway without the air barrier that approximates the energy savings seen in Pathways 7 through 11, all of which have the air barrier. The fact that Pathway 3 is the one with energy savings in the range of those with higher savings reveals the other dominant component for energy savings; that is the heat recovery

TABLE 4.13. Regional Energy Savings by Housing Type for the Proposed Action Pathways (Average Megawatts), 1986-2006

Pathway	Single-Family Upper Bound	Single-Family Lower Bound	Multifamily Upper Bound	Multifamily Lower Bound	Manufactured Housing Upper Bound	Manufactured Housing Lower Bound
1	117	107	36	29	37	36
2	108	87	32	22	35	34
3	116	95	35	26	35	33
4	80	74	16	11	37	35
5	99	93	28	23	29	28
6	102	99	29	25	32	31
7	142	134	39	31	33	32
8	130	114	36	27	41	40
9	139	120	39	30	40	38
10	115	99	22	13	40	39
11	134	119	33	25	35	34

component of the AAHX. Note that Pathway 3, with MVHR, saves some 17 MW, or 17% more energy than Pathway 5, which has a mechanical exhaust system instead of an AAHX, but is otherwise identical to Pathway 3. And, Pathway 8, which has an AAHX, saves some 15 MW, or 13% more energy than Pathway 10, which also differs only by having a mechanical exhaust system instead of an AAHX.

It also appears that the heat recovery aspect of the AAHX is a factor in lessening the effect of the difference between operating the MV system continuously or intermittently (8 hr/day). That difference results in a loss of some 19 MW with an exhaust system (Pathway 4 to 5 or Pathway 10 to 11), but only 12 MW are lost from Pathway 2 to 3, and only 9 MW are lost from Pathway 8 to Pathway 9. Thus the penalty attached to continuous mechanical ventilation is about 2 times more with an exhaust system than with an AAHX. Energy savings for Pathway 6 are slightly overestimated because we do not account for the installation of ports in any number of houses.

4.3.2 Costs

We estimated the incremental costs of adding energy-efficient features to new single-family, multifamily, and manufactured homes to those presented in Table 3.8. Costs of the No Additional Action and each of the pathways in the Proposed Action were analyzed through a comparison between the pathway and the baseline home. The cost of each pathway is constructed by adding the costs of energy-efficient features, the appropriate ventilation features and their installation requirements, radon source control measures, and radon monitoring to the baseline home.

The insulation package making a home energy-efficient is a key factor that distinguishes the alternatives from the Baseline. The analysis assumed that the average residential unit is 1400 sq. ft. For other assumptions used in the analysis, as well as a description of the methodology and the costs of the various measures, see Appendix E.

Each of the components of the pathways was examined individually. The purchase and maintenance costs for both retrofit and source control construction cases were weighted by the number of houses in each category over the 20-year period to find the cost stream associated with each component. The present value of this cost stream was found using a discount rate of 3%. There was one exception to this procedure: the insulation package. The insulation is needed for each of the pathways since they are all based on a more energy-efficient house than homes built to 1983 practice.

The resulting costs are shown in Table 4.14. The most expensive pathways are 8 and 9, followed closely by Pathways 2 and 3. These pathways are all $522 to $497 million dollars. Pathways 10 and 11 are about $100 million less expensive. The next set of pathways, 4, 5, and 6, is again a little more than $100 million less than the second group, although Pathway 6 costs more. Pathway 6 is more expensive because of the required blower door test, the additional installation requirements of a larger fan and accompanying ductwork, and the assumption that 30% of the houses will be retrofit with an average of four ports. The cheapest pathway, as might be expected, is

TABLE 4.14. Regional Cost of the Alternatives (1986 Millions $)

Measure	No Additional Action	Proposed Action Alternative Pathway 1	Pathway 2	Pathway 3	Pathway 4	Pathway 5	Pathway 6	Pathway 7	Pathway 8	Pathway 9	Pathway 10	Pathway 11	Preferred Alternative
Large AAHX		$0	$268	$268	$0	$0	$0	$0	$0	$0	$0	$0	
Small AAHX 8 hr		$0	$0	$0	$0	$0	$0	$0	$171	$171	$0	$0	
Exhaust Fan with ports 24 hr		$0	$0	$0	$14	$0	$0	$0	$0	$0	$14	$0	
Exhaust Fan with ports 8 hr		$0	$0	$0	$0	$14	$0	$0	$0	$0	$0	$14	
Air Barrier		$0	$0	$0	$0	$0	$0	$122	$122	$122	$122	$122	
Exhaust Fan With ducting		$0	$0	$0	$0	$0	$63	$0	$0	$0	$0	$0	
Ventilated Crawlspace		$4	$4	$4	$4	$4	$4	$4	$4	$4	$4	$4	
Gravel		$21	$21	$21	$21	$21	$21	$21	$21	$21	$21	$21	
Monitoring		$4	$4	$4	$4	$4	$4	$4	$4	$4	$4	$4	
Insulation Package		$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	
Blower door test		$0	$0	$0	$0	$0	$26	$0	$0	$0	$0	$0	
Ports		$0	$0	$0	$25	$25	$8	$0	$0	$0	$25	$25	
Regional Expenditure	$233	$229	$497	$497	$268	$268	$326	$351	$522	$522	$390	$390	$379

Pathway 1, with a regional cost of $229 million. These costs do not reflect the program's administrative costs.

4.3.3 Fuel Choice

Fuel choice refers to the decision made by new home builders, buyers, or renters regarding the selection of electricity or alternative fuels for space heating. From an economic standpoint, two considerations influence this decision.

On one hand, building to energy-efficient standards is expected to raise the price of new electrically heated homes from $.56 to $1.48 per sq. ft. over the price of a standard home. The sale price of a 1,848-sq. ft. house is expected to increase by $1,567 to $2,727. If homes with other heating fuels are not built to energy-efficient standards, they will have a first-time cost advantage over energy-efficient, electrically heated homes. This may result in people choosing fuel types other than electricity. On the other hand, building an energy-efficient home is estimated to reduce electricity use by 26% to 58% for single-family and by 10% to 27% for multifamily homes. This would reduce operating costs. Hence, the first-time sale price increase of an energy-efficient house must be weighed against the decrease in operating costs. If the fall in the net present value of life-cycle operating costs is greater than the increase in the sale price, and consumers can afford the higher first-time costs, then informed consumers may choose electric heating over alternative fuels, if the alternative fuels are in homes that are not energy-efficient.

If incentives are pa$ to builders or buyers of new energy-efficient electrically heated homes, the first-time costs are effectively lowered. If a payment is offered that is equal to or greater than the rise in the sale price, it would create an incentive to choose electricity over other fuel types. In BPA's 1986 medium forecast, the level of incentive at which no fuel switching occurs is estimated to be between $1,000 and $1,500. At this incentive level, the reduced energy costs of energy-efficient features balance the increased first cost of installing the features.

Another factor is people's perceptions of energy-efficient homes. Surveys focusing on home selection and attitudes toward conservation have generally not identified concerns about IAQ or effects on health and safety as a factor in decisions or attitudes. But should consumers begin to associate these problems with energy-efficient MCS houses, there could be some shift of consumers to choose less energy-efficient houses that use alternative fuels.

The number of consumers choosing another fuel for space heating because of energy-efficient standards for electrically heated homes is shown in BPA's 1986 medium forecast of new home additions. The estimated number of new electrically heated single-family and multifamily homes built from 1986 through 2006 is:

- Baseline (no energy-efficient homes programs) - 960,226 homes

- No Additional and Proposed Action Alternative (energy-efficient standards with incentives) - 790,621 homes

The differences among these figures are attributed to consumers choosing another fuel instead of electricity. Moving from no program to a program with incentives results in 169,605 single-family and multifamily dwellings, or close to 18% of the Baseline, that otherwise would have chosen electricity, choosing another fuel.

Heating a home with electricity requires generating electricity at a power plant. The effects of using fuel at a generating plant to produce electricity are compared with the effects of burning fuel oil and natural gas in homes in Table 4.15. In this table all the impacts of electricity production, except radiation exposure, which is associated with nuclear power plants, are associated with coal-fired generation plants. It is important to note that coal-fired plants are currently considered fifth in the line of generation resources that may be used if the electrical load reduction from

TABLE 4.15. Environmental Impact Coefficients of Using Electricity, Oil, or Natural Gas to Heat Residences That Switch Fuels Under the No Additional Action Alternative (169,605 Dwellings)

Sector and Impact	Electricity[(a)]	Oil	Natural Gas
Particulates (thousand tons)	0.236	0.177	0.0
Nitrogen oxides (thousand tons)	3.717	0.413	0.767
Sulfur dioxides (thousand tons)	2.065	0.767	0.0
Hydrocarbons (thousand tons)	0.059	0.177	0.0
Solid waste (thousand acres)	531.0	0.0	0.0
Land use (thousand acres)	5.31	2.36	0.59
Radiation exposure (thousand man-rems)	0.301	0.0	0.0
Occupational injuries (persons)	3.481	0.059	0.118

(a) All impacts of electricity production, except radiation exposure, are associated with coal-fired generation plants. Radiation exposure is associated with nuclear power plants.

new energy-efficient homes is not realized. Resources that would be used first include other conservation, then combustion turbine generators, small hydroelectric projects, and cogeneration plants. Impacts of these resources are given in Section 4.5.

Table 4.15 compares regional environmental impacts of the consumption of electricity with impacts from consumption of fuel oil and natural gas. The impact coefficients were originally calculated by Charles River Associates (1978) by arbitrarily reducing the consumption of each of three energy forms and computing the resulting change in impact per trillion British thermal units (Btu). Switching from a fuel with a higher coefficient to one with a lower coefficient for a given impact would, on average, reduce the amount of that particular impact.

Rather than showing impacts per trillion Btu, we adjusted the coefficients to match the energy requirements of the houses projected to switch fuels under the No Additional Action Alternative. The coefficients shown in Table 4.15 are for "impacts per 5.9 trillion Btu," which is the energy needed to heat the homes forecasted to choose other fuels under the No Additional Action Alternative (169,605 homes), assuming that an average home requires about 35 million Btu per year for heat (NWPPC 1986).

Space heating with oil or natural gas generally results in less impact (fewer pollutants) than does electricity, assuming it is generated at a coal-fired plant, but the pollutants from burning fossil fuels in homes will be nearer to population centers rather than at more remote central electric generating plants. In addition to the impacts shown, the use of fossil fuels could cause other effects. Additional conventional onshore exploration and extraction of oil or natural gas may cause fracture of underground aquifers, soil erosion, decreased soil fertility. and possible stream sedimentation (BPA 1983). There is also the possibility of spills from drilling and transporting oil.

4.3.4 Housing Affordability

Adding energy-efficient features to new homes increases the first cost that consumers must pay for that home. An energy-efficient single-family home is expected to cost approximately $.56 to $1.48 more per square foot of heated space than a current practice home. This is roughly a 1.3% to 3.3% increase over the median consumer price of $44.45 per square foot (excluding land) for homes constructed in 1984 in the western United States(a).

(a) In a personal communication on September 4, 1986, Tom Eckman of the Northwest Power Planning Council staff gave a qualitative professional estimate of between $40 and $45 per square foot as the median consumer price of new homes built to 1983 practice in the Northwest. According to 50 Federal Register 30659, July 26, 1985, the median consumer price per square foot for homes constructed in 1984 in the western United States (excluding land) was $44.45 (Bureau of the Census 1985, Table 20). For more information see Economic and Social Effects of Model Conservation Standards, Appendix D in Vol. II of the DEIS.

This increased cost over that of current practice homes includes the cost of installing increased insulation, more energy-efficient windows, and mechanical exhaust systems, as specified for the MCS. This cost does not cover the optional approach allowable under the No Additional Action (air barrier and AAHX). The cost for the Proposed Action Alternative varies because of the different infiltration and ventilation systems which compose the pathways. Some of the costs will be greater because whole-house mechanical ventilation with heat recovery is specified. In other cases, the costs will be much less because no mechanical ventilation is required. The estimated costs of the alternatives are given in Section 4.3.2.

The impact of this added cost is likely to be greatest on first-time home buyers who are at or near the margin of qualifying for financing to purchase a new home. However, several factors will minimize this effect. First, most buyers of new homes are not first-time buyers; therefore, the group most likely to feel the brunt of increased costs is relatively small. According to the National Association of Home Builders, only about 26% of newly constructed homes in the western United States sold between July 1978 and June 1979 were purchased by first-time buyers, although this was a national survey and is not directly applicable to the Northwest. However, a survey of eleven major metropolitan areas showed that in 1985 only 16.5% of new homes in the Seattle area were purchased by entry-level buyers (Pfister 1986). The remainder were presumably purchased by buyers able to apply equity from previously owned homes to the purchase of new ones.

A second mitigating factor is that many lenders are relaxing their loan underwriting standards for buyers of energy-efficient homes. Both the Federal Home Loan Mortgage Corporation and Federal National Mortgage Association, two leading secondary market purchasers of home loans, have relaxed their underwriting guidelines for energy-efficient dwellings. The expectation is that buyers of these homes will have lower utility costs and, consequently, more income available to pay their mortgage debt.

The Federal Home Loan Mortgage Corporation has endorsed Super GOOD CENTS (SGC) homes, the type of energy-efficient homes promoted by BPA, and will accept loans in the secondary mortgage market with higher debt to income ratios for these homes (BPA 1986b). Previous BPA studies have found that when lenders are able to identify energy-efficient homes, they have sometimes been willing to relax loan/income ratios for buyers by 2 to 4% (Bonner 1984, 1985).

A third factor that will offset the additional cost of energy-efficient features is incentive payments. Payments offered to encourage construction of energy-efficient homes will effectively lower the purchase price of new homes and make it easier for new home buyers to qualify for financing. Our analysis assumes that BPA is offering payments for the construction of single-family and multifamily SGC homes for the period from January 1986 through 1988. The levels of incentives are outlined in Table 4.16. Incentives are not offered for manufactured homes.

Finally, the cost of building energy-efficient homes is expected to drop as builders gain more expertise in installing and using special features and

TABLE 4.16. Builder Incentive Levels[a] for the Construction of Super GOOD CENTS Homes (1986-1988)

Housing Type	Climate Zone 1	Climate Zone 2	Climate Zone 3
Single-Family (without AAHX)	$1,000	$1,250	$1,500
AAHX option per unit	500	500	500
Multifamily			
First unit	1,000	1,250	1,500
Per additional unit	250	250	250
AAHX option per unit	500	500	500

(a) Program incentive levels are subject to change.

techniques, and as the market for special products becomes better established and more competitive.

Renters can also expect to pay more for a dwelling built to energy-efficient standards. However, most renters will also directly realize the benefits of such standards through reduced utility bills. In the Northwest, 88% of tenants in buildings with five or more units pay their own electric bills. This percentage is likely to be even higher in newly built energy-efficient multifamily structures.

In spite of mitigating factors, some prospective home buyers will be unable to purchase the energy-efficient homes they desire. However, they will not be precluded from buying a home. Several options are available to them. One option is to buy an existing home not built to energy-efficient standards. Another option is to buy a home heated with an alternative fuel in communities where these homes are not built to energy-efficient standards. A third option is to trade off another desired amenity for increased energy efficiency. The list of possible tradeoffs is long and includes such things as a slightly smaller home or a lower-priced lot. Prospective renters affected by higher rents have similar options.

The increased costs of building energy-efficient manufactured homes are not as well studied as those for single- and multifamily homes. But increased costs should have similar effects. However, unlike site-built homes, which meet local codes, manufactured homes are built to meet a national code promulgated by HUD.

As part of the design process under the HUD code, builders must certify that their designs for manufactured homes meet minimum requirements. A manufacturer's cost of having modifications to existing designs checked ranges from $100 to $250, and if totally new designs are checked, the cost is between $700 and $1200 (Balistocky, Lee, and Onisko 1986). These costs will be incurred under all of the alternatives except the Baseline. The costs will be passed on to consumers but may be spread over many units with minimal impact on any one purchaser. And, as designs change over time to match consumer taste, energy improvements may be made concurrently with other changes. Under these circumstances the costs of the design check may be the same regardless of the presence of energy-efficiency improvements.

4.3.5 Employment

Summarized below are five general means by which a conservation program is likely to affect employment levels:

- Direct employment is the most obvious effect. Building new homes to more stringent standards requires more labor hours, resulting in increased demand for construction labor. And, as demand for regionally produced building materials to meet the standards increases, demand for labor to produce those materials will increase.
- Indirect employment results from increased output in industries that supply producers of building materials.
- Induced employment effects occur as income earned via the direct and indirect effects is spent on regionally produced goods and services.
- Implementing energy-efficient standards may also increase employment because of inspection and enforcement requirements.
- Finally, implementing energy-efficient standards may affect disposable income both positively and negatively, which, in turn, affects regional employment. Negative income effects result from increased costs of buying energy-efficient homes and the overall costs of program administration and enforcement. Positive effects on income arise from the lower life-cycle cost of an energy-efficient structure compared to that of one built to current practice.

A study conducted by Sims (1984) for the Northwest Conservation Act Coalition found that avoiding future load growth by instituting the MCS would have a more positive impact on regional employment than generating an equivalent amount of electricity with a coal plant. The study drew on a methodology developed by Charles River Associates (1984) for BPA to assess the economic effects of weatherizing existing homes. We used Sims' study to estimate qualitatively how each of the alternative actions would affect employment.

However, two caveats must be recognized in interpreting Sims' model. First, the figures apply only to the period from 1992 to 2002. Sims did not count increased employment from 1986 to 1992, nor did Sims count gains from 2002 to 2005. Thus, the figures understate potential employment gains. Second, the calculations were predicated on a 90% penetration rate of energy-efficient features in new electrically heated homes. For comparison, the energy savings and health effects analyzed in this EIS are predicated on a penetration rate of 75%. Hence, Sims'assumed penetration rate is optimistic and overstates the employment effects. Given these two considerations, which are not easily evaluated one to the other, along with other characteristics of Sims' model, we could not quantify the employment effects of the alternatives. More information about our analysis is given in Appendix F.

Sims' conclusions may be summarized as follows:

- More employment is produced by the buying of goods and services than by the purchase of energy resources (both conservation and generation).
- Assuming that electric load grows, less employment would be lost by purchasing MCS to reduce load growth than by building a coal plant to generate electricity to serve load growth.

Sims' analysis does not account for the installation of mechanical ventilation with heat recovery such as AAHXs. But if mechanical ventilation is required, as it is for the most part in the No Additional Action and in some of the pathways of the Proposed Action, the cost of building energy-efficient homes is greater. This added cost reduces the disposable income available for other goods and services and leads to a greater negative effect on employment levels. This relationship between increased cost of the MCS, which results in increased effects on employment, is used to rank the alternative actions. These are summarized in Table 4.17.

4.3.6 Shelter Industry

The discussion on the shelter industry is divided into two parts, one dealing with site-built homes and one with manufactured, or factory-built, homes that are transported to the site. Like the changes in employment described in Section 4.3.5, there is not enough information available to quantify effects on the shelter industry; thus, this is a qualitative discussion.

Alternative Actions

Other than the Baseline, which represents existing conditions, each of the alternatives has essentially the same effect on the shelter industry in that energy-efficient features are incorporated into building practices. The one factor that changes among alternatives is the flexibility provided by the Proposed Action of choosing options for maintaining IAQ. Although each of the alternatives requires that builders follow some requirements to protect IAQ, some options are more sensitive to installation than others. The sensitivity of IAQ mitigation techniques to installation was presented in Table 3.29; for example, mechanical ventilation with heat recovery, such as that with an AAHX, is shown as highly sensitive. This is an option in the No Additional Action and in some of the pathways under the Proposed Action. However, other pathways allow options which are less sensitive, and thus are less likely to require new technical skills.

Single-Family and Multifamily Homes

The home building industry is a complex assortment of general contractors, subcontractors, architects/designers, manufacturers, regulators, financiers, marketers, and buyers. Such complexity indicates that complementary changes by a large number of organizations and individuals are needed to achieve improvement in residential energy conservation. However, the New Energy-Efficient Homes Programs do not appear likely to cause major changes in the structure of this system. No major new participants are needed, and none of

TABLE 4.17. Employment Effects of Various Alternatives

Alternative/Pathway	Impact
Baseline	None
No Additional Action Alternative	
Exhaust System with Ports	Reduced employment under both energy surplus and deficit because electric bills are higher than in the baseline; thus consumers spend less on other goods and services,
AAHX with Air Barrier	Larger net negative employment compared with exhaust system because AAHXs cost more; therefore, it will have greater effect on electric bills and consumers' ability to spend on other goods and services as larger number of AAHX systems are installed.
Proposed Action Alternatives	
Pathway 1	Employment reductions are less than under No Additional Action because mechanical ventilation is not required; thus, costs are lower, bills are lower, and the reduction in spending on goods and services is less.
Pathways 2 and 3	Similar to AAHX system option under No Additional Action, but since there is no air barrier, net negative effects would be less.
Pathways 4 and 5	Similar to the exhaust system option under No Additional Action.
Pathway 6	Similar to Pathway 5, with slightly less unemployment because of blower door tests.
Pathway 7	More unemployment than Pathway 1 because of requirement for air barrier, which increases costs and bills, and thus decreases expenditures on goods and services.
Pathways 8 and 9	Similar to the AAHX option under No Additional Action.
Pathways 10 and 11	Similar to Pathways 4 and 5 but greater because of the costs of the air barrier.

the existing participants are likely to be eliminated. However, participants will need to adjust their practices and possibly learn to work with new materials to meet energy-efficient standards.

The nature of the shelter industry, in which a single construction project involves many relatively autonomous actors, raises questions about the impact an energy-efficient homes program may have on the organization of the industry. Builders indicate that construction of highly energy-efficient buildings requires more careful planning, sequencing, and coordination of the production process. At least during the "learning period," construction of energy-efficient homes also requires greater supervision of employees and subcontractors. This suggests modification of the traditional division of authority and responsibility in the home building industry, in which general contractors have limited managerial influence and subcontractors make many of the decisions and control many of the procedures important in constructing energy-efficient buildings.

However, the relationship among participants in the home building industry is generally flexible. Workers typically demonstrate a willingness and ability to adjust tasks and responsibilities to accommodate the requirements of energy-efficient building techniques. This flexibility, and the point that accommodations are required of nearly all participants in the process, confers a resilience on the industry. Because of its resiliency, if adequate training and information are given to specialty trades and contractors, the shelter industry should be able to accommodate the changes needed to build energy-efficient homes without substantial reorganization. However, changes required to meet the standards and the fragmented nature of the industry suggest that the learning period during which effective materials, techniques, and procedures are established may be long.

Manufactured Homes

Manufactured homes are built at a factory and transported to the dwelling site. Because all phases of construction occur at a factory, it is easier to control the manufacturing process and accommodate changes in the physical character of the structures when the changes apply to a large number of homes being produced. BPA has sponsored limited studies and found that manufactured homes can be built to energy-efficient standards without major changes in current construction practices (Levy 1986).

However, in five energy-efficient manufactured homes that BPA had built for research purposes, the whole-house AAHXs were not well integrated into the home design, were improperly sized, and not optimally installed(a). For example, the heat exchangers were all located on the floor of a bedroom closet, the vents located in the floor, and all duct work run under the home. The added floor insulation prevented the use of rigid metal duct work in the floor joist channels and necessitated the use of insulated plastic flexible ducting mounted on the exterior of the moisture barrier membrane.

(a) Telephone conversation with G.B. Parker of PNL, October 9, 1986.

Builders of manufactured homes are required to offer mechanical ventilation options with each home (HUD 1984). Most offer an AAHX as one of several ventilation options, but most of the AAHX installations are single wall-mounted units since the required ventilation is a minimum of 40 cfm fresh air. A typical wall-mounted unit will deliver 50-80 cfm. A whole-house AAHX typically delivers more than 100 cfm, twice as much as required and at a much greater consumer cost. For these reasons, few whole-house AAHX systems are offered or installed in new manufactured homes. Builders thus have less experience in the design and installation of a whole-house AAHX of the size (100 cfm) used in the BPA study. This suggests that more training, installation experience, and improved whole-house AAHXs, specifically for energy-efficient manufactured homes, are needed to better integrate them into new homes.

Liability

Builders have asked about the liability which might result from meeting energy-efficient standards. The question of legal liability is not an "environmental effect" of the new energy-efficient homes proposal. BPA cannot provide legal advice to builders and building materials producers. Four references currently are available on this subject: (1) "Local Government Liability and the Model Conservation Standards in Washington State," Association of Washington Cities, Washington State Association of Counties, February 1985; (2) Oregon Attorney General's opinion, June 25, 1984; (3) "Liability Aspects of House Energy Rating Systems," Pacific Northwest Laboratory, prepared for the U.S. Department of Energy and available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; and, (4) "Potential Liability for Indoor Pollution," Earon S. Davis (1986), presented at the 79th Annual Meeting of the Air Pollution Control Association (APCA), available from APCA for $2.50 at P.O. Box 2861, Pittsburgh, Pennsylvania 15230.

Despite questions about liability, some builders are already constructing MCS homes. During the last 3 years, approximately 2400 single-family dwellings and 4770 multifamily units have been built through BPA programs for promoting construction of MCS homes. It is thus reasonable to infer that some builders are willing to build according to energy-efficient standards even though some have expressed concern about possible increased liability. This concern may reflect as much fear of the unfamiliar and untried as it does genuine concern about liability. BPA hypothesizes, based on studies of perception of risk, that after a few years' experience, builders who currently express concern about liability under MCS will be much less concerned (Allman 1985; Alvord and Eaton 1979).

4.3.7 Behavioral Changes

Surveys have shown that home buyers are aware of energy-efficient characteristics in homes and that residents of the Northwest generally view conservation favorably. However, households are complex living environments, and the achievement of energy-efficiency may require adjustments in behavior and lifestyle by residents. Although little information is available about behavior modification in energy-efficient homes, several features that may require adjustments have been identified.

Residents in homes with low ventilation rates may need to be more aware of potential pollution-producing activities. Low ventilation rates increase the potential of certain household activities, such as bathing, cooking, cleaning, and keeping plants, to raise humidity above desirable levels. Household activities such as cooking, smoking tobacco, working on hobbies, and burning wood may also create high pollutant concentrations.

However, ventilation rates are not entirely tied to energy efficiency features. All homes are likely to have periods of low ventilation because of low wind speed and moderate temperature differences between indoors and outdoors. Builders may construct tight homes in the absence of BPA programs.

Furthermore, while ventilation is a factor in determining pollutant levels, other factors, such as the source strength of pollutants, also have a role to play. So, while residents of tight homes need to be cognizant of potential sources of pollution, so do other consumers, and increased awareness is needed across all of the alternatives, including the Baseline. To help foster this awareness, BPA requires that home buyers participating in its new homes programs (No Additional Action and Proposed Action Alternatives) receive educational booklets describing the dynamics of IAQ, the sources of pollutants, and ways of mitigating different types of pollutants.

In homes with MV systems, residents may need to be more diligent about using fans and vents and pay more attention to maintaining and servicing equipment. However, these issues are not limited to energy-efficient homes and are beginning to be addressed by automatic controls such as humidistats. Ventilation devices are not required in baseline homes, but spot ventilation such as kitchen and bathroom exhaust fans are often installed, and the consumer must operate and maintain them. However, this type of equipment is generally not as complex as the whole-house MV systems required under the No Additional Action and some pathways in the Proposed Action.

Under the No Additional Action, ventilation devices are required in tight homes. In those cases where the devices must operate continuously, consumers need not worry about turning the devices on and off unless they choose to, although they need to maintain the equipment for proper operation. Where the MV system is operated intermittently, occupants must make a conscious effort to turn on the system.

The purpose of the Proposed Action Alternative is to allow more flexibility for builders and consumers in choosing ways to protect the quality of indoor air. This Alternative includes options for <u>not</u> installing mechanical ventilation and, where they are installed, more flexibility in their operation is allowed. The intent of this action is to allow builders and consumers to choose pathways with which they feel the most comfortable.

The most that can be said at this stage is that there is a potential for energy-efficient construction to affect residents' behavior, but the effects are not well understood. Offsetting these changes are positive contributions to residents' well-being such as more control over their environment, increased comfort resulting from less draft, and lower utility bills.

4.3.8 Institutional Effects

Implementation of the Energy-efficient Homes Programs as defined under the No Additional Action and Proposed Action Alternatives will require inspections to ensure that standards are being met. This will add new regulations and requirements that will increase the size, presence, and control of government at the local and regional levels. The imposition of standards may also increase the bureaucratization of utilities and/or local governments in the region.

4.4 HEALTH AND SAFETY ISSUES UNRELATED TO INDOOR AIR QUALITY

This section describes other impacts on health and safety which might result from the construction of energy-efficient homes. The section focuses on impacts of manufacturing and using materials needed to implement the New Energy-Efficient Homes Programs; these materials include insulation, additional window glass, and framing. In our discussion of heat pumps, we address both noise pollution and the effect on the ozone layer of the materials used as refrigerants in the heat pumps.

4.4.1 Increased Insulation and Potential Fire Hazards

In public meetings to determine the scope of this EIS, some people expressed concern that increased insulation in energy-efficient homes may contribute chemically hazardous fuel to fires. No increased risk of home fires has been associated with energy-efficient construction, according to representatives of three insurance companies, Underwriters Laboratory, the National Fire Protection Association, and the King County Fire Marshall's Office.

Cellulose insulation has been identified as a potential fire hazard, even when treated with fire retardant chemicals. Evidence of potential degradation in fire retardant performance through sublimation of the fire retardant additives has been observed in cellulose insulation which has been subjected to environmental cycling. Some settling out of the dry fire retardant salts has also been observed although this phenomenon has not been linked to an increased fire hazard in cellulose insulation. Tests performed by U.S. Borax of the permanency of borate fire retardant additives seem to indicate adequate, long-term fire resistance should be maintained in insulation which conforms to federal insulation flammability standards. Care must be taken with cellulose, as with any other type of insulation material, to prevent excessive accumulation of heat in insulation surrounding heat sources by inspecting for overloaded wiring, and by maintaining adequate clearance around recessed lighting, fireplace flues, and other potential sources of heat. Properly installed cellulose insulation which conforms to federal standards remains a safe and effective insulation.

Polyurethane insulation has been identified as a potential source of highly toxic fumes during fires. However, the smoke from polyurethane is similar to smoke from the burning of flexible urethanes used in chair cushions, mattresses, couches, and other home furnishings.

As a source of additional fuel, insulation should be inconsequential. In a typical residential setting there are 3 to 8 lb of fuel per sq. ft from the house structure and furnishings (Fang and Breese 1980). Assuming 5 lb per sq. ft, a 1,600-sq. ft residence has 8,000 lb of combustible material without counting insulation. Increased insulation needed to meet the energy-efficient standards of the No Additional Action and Proposed Action Alternatives will add a small increment to existing combustibles; these insulation materials are already being used in current practice homes built under the Baseline.

The question of insulation producing noxious fumes is uncertain. Levin and Purdom (1983) reviewed the health effects of materials used in home insulation and noted that some of these materials may present hazards to installers, firemen, and maintenance and repair personnel. Asbestos, cellulose, and polyurethane were identified as hazardous. Cellulose was identified as a potential fire hazard, even when treated with fire retardants, and polyurethane was identified as having potential to produce highly toxic material during thermal decomposition. If such hazardous materials are not used, however, there is no indication that the MCS would increase the risk of home fires. Other information (Hadley 1986) refutes the statement that polyurethane has the potential to produce highly toxic materials during thermal decomposition. According to Hadley, work done at the University of Pittsburgh indicates that the toxicities of the various forms of polyurethane are similar to those for Douglas fir and natural wood.

4.4.2 Rigid Foam Polyurethane Insulation

Closed cell polyurethane foam insulation is made with the compound trichlorofluorethane (F-11), a compound thought to contribute to reducing the ozone layer in the atmosphere. The ozone layer shields the earth from the ultraviolet radiation being continuously emitted from the sun. Depleting atmospheric ozone may lead to global warming and increased flooding from melting of the polar ice caps due to the greenhouse effect, and to increased cases of skin cancer from exposure to ultraviolet radiation.

Khalil and Rasmussen (1986) suggest that F-11 emissions from rigid closed cell polyurethane foam (CCPUF) insulation may greatly increase in the future as a result of building new energy-efficient buildings. Emissions occur initially as sheets of the material are cut into smaller pieces, releasing gas trapped in the foam. After installation, emissions occur at a much slower rate as the material ages. However, it is not possible at this time to quantify how much of an impact F-11 from CCPUF has on the ozone layer.

CCPUF insulation acts as a long-term reservoir and source of F-11 after the insulation is installed. It is uncertain how long CCPUF insulation will remain in use after installation, but it could be up to 80 years (Rand 1980). Once removed from use, all remaining F-11 that has not been emitted to the atmosphere is released if the foam is burned or destroyed. If the foam is buried, F-11 will continue to leak slowly from the foam.

There are alternatives to using F-11 in manufacturing rigid polyurethane foam insulation, and at least one manufacturer is using an alternative compound. However, we are unsure what the substitute compound is made of, and what its environmental effects may be. At present, there is a great deal of uncertainty about the effectiveness and potential environmental impacts of possible alternatives to ozone-depleting compounds (Doniger and Wirth 1986).

The environmental effects of each of the alternatives are not quantifiable, but should be essentially the same for any given home, since insulation requirements are identical. However, as the number of energy-efficient homes changes among the alternatives, the impacts will change accordingly.

4.4.3 Mineral and Wool Insulation

Under the Baseline, no additional quantities of insulation are required above the normal demand for residences built to existing building code; therefore, no additional pollutants are emitted to the atmosphere, and no additional impacts to the ambient air quality levels are expected.

Under the No Additional Action Alternative, additional quantities of insulation will be required in homes built to MCS. The amount of additional insulation needed is considered to be directly proportional to the maximum amount of energy acquired (132 MW), which is directly related to the number of energy-efficient single- and multifamily homes built to MCS. The amount of pollutant emitted to the atmosphere is directly related to the amount of insulation material produced multiplied by an emission factor that is based on the process used to produce the material. For purposes of this assessment, we consider fiber glass, rock wool, or cellulose as insulation material. Of these choices, emission factors have been developed for the production of fiber glass and rock wool. During production of both of these insulation materials, the primary pollutant emitted to the atmosphere is particulates. If we assume the amount of insulation material is either all cellulose or all rock wool, the amount of total suspended particulates (TSP) emitted to the atmosphere would be 93.5 tons or 18.2 tons, respectively. These amounts represent 0.0000322 and 0.000008% increases in the total estimated energy-related particulate emissions for the 20-year period if we assume emission data from 1986 is representative of each year.

Under the Proposed Action, the amount of the energy resource acquired would depend on the pathway chosen under this alternative (96 to 181 MW). Using the same approach as used for the No Additional Action, the amount of particulate emitted to the atmosphere ranges from 63 to 116 tons if cellulose is produced to meet the additional demand in insulation. If only rock wool is produced to supply the additional insulation need, the amount of particulates emitted to the atmosphere would be 15.9 to 29.3 tons. These amounts represent an increase of from 0.000008 to 0.000033% in the total estimated energy-related particulate emissions based on 1986, the last year for which data are available.

In the Preferred Alternative, the amount of the energy resource acquired would depend on whether the upper or lower estimate of ventilation rate was most appropriate (140 to 124 MW). Using the same approach as used for the No Additional Action, the amount of particulate matter emitted to the atmosphere would be 99.2 tons if cellulose was produced to meet the additional demand in insulation. If only rock wool was produced to supply the additional insulation need, the amount of particulates emitted to the atmosphere would be 17.1 tons. These amounts represent increases from 0.000034 to 0.0000075% in the total estimated energy-related particulate emissions over the period of the program.

4.4.4 Passive Solar Materials

The passive solar features incorporated in Bonneville's new homes programs (BPA 1985) require neither unique building components nor special design considerations that would pose health or safety problems. The solar option is met by installing specified amounts of south-facing glazing, and matching the glazing with an appropriate amount of thermal mass. The extra glass allows heat from the sun to enter; the thermal mass stores the heat and minimizes wide temperature swings. The solar option does not include any provision or give any credit for features such as solar collectors.

For the most part, glazing used for the solar option is identical to other glazing used in the new homes programs and must meet the same criteria. This is true even in the case of opaque walls, where the glazing covers and the thermal mass are combined as part of the wall, and the glazing is not used as a "window." As either a typical south-facing window, or as part of an opaque wall, the glazing does not adversely affect the human environment. The solar glazing creates no more a hazard than any other window in a home built to the energy-efficient specifications. Like any other windows, solar glazing must be installed to meet local building codes.

The other unique feature of the passive solar option is the requirement for thermal mass. Materials that may be used for this purpose include hard-surface slab floors, masonry walls, gypsum board plaster walls and ceilings, and water walls. Of these materials, only water walls are not likely to be found in typical new homes. Water walls consist of a structure to hold water such as tubes or custom designed containers. Water walls that are part of the house structure must meet local building codes, and are likely to be built out of common materials such as acrylic, fiber glass, or metal.

Typical building materials can be used to meet solar glazing and thermal mass requirements. Where builders elect more customized approaches such as opaque walls or water walls, local building codes designed to protect public health must be met. The components of these features are likely to be common materials. Therefore, the use of solar options will not result in any adverse environmental effects.

Some members of the public expressed concern that reduced window area could potentially block escape during a fire. Energy-efficient standards are designed to coexist along with the Uniform Building Codes (UBC), which specify minimum window sizes that can be installed and still serve as a means of exit. The UBC also specifies how many exits are required. Homes now being built in the Northwest that follow UBC safety requirements have window areas equaling

8 to 10% of floor area. BPA's current energy-efficient standards allow glazing to equal up to 15% of floor area. Since all UBC safety requirements regarding the number and size of exits must be met, exit from homes built under the No Additional Action and Proposed Action Alternatives should be no more difficult than from baseline homes meeting current code requirements.

4.4.5 Window Glass and Frames

For purposes of assessing the impact of window production on outdoor air, we assume that all improved window thermal efficiency is achieved by installing triple-pane glass in aluminum frames, and that total allowed glass area within a structure increases from 10% under baseline conditions to 15% under BPA's programs.

Under the Baseline, no additional glass beyond normal requirements would be produced. The total amount of glass area within a structure is typically 10% of the floor area. Under this alternative, a maximum of 314,190 tons of glass would be produced, increasing the amount of TSP now emitted to the ambient air. The amount of TSP estimated to be emitted to the air over the life of the program would represent a 0.0000086% increment in the amount now estimated to be emitted annually to the atmosphere in the United States. Comparing these emissions to emissions from the region is not appropriate, as most U.S. glass production occurs outside the Northwest.

The manufacturing of glass windows requires the manufacture of aluminum for the window frames. It is estimated that 51,159 tons of aluminum would be required over the 20-year period. Production of this amount of aluminum will create 0.26 tons of particles that would be released to the atmosphere on an annual basis, assuming an emission rate of 0.2 lb/ton of aluminum (EPA 1973). Most of the aluminum is expected to be produced in the region.

If the No Additional Action or Proposed Action Alternative is chosen, additional glass may be produced, considering that the total amount of allowable glass area within a structure may increase to approximately 15% of the floor area. If this does occur, a maximum of 73,020 tons of additional glass may be produced and would increase the amount of TSP emitted to the ambient air. The amount of TSP estimated to be emitted to the air would represent a 0.00000204% increment in the amount estimated to be emitted annually to the atmosphere in the United States.

The additional glass windows manufactured under these alternatives will require an estimated 21,473 tons of aluminum manufactured for the window frames. Production of this amount of aluminum will create 0.11 tons of particles that would be released to the atmosphere on an annual basis, assuming an emission rate of 0.2 lb/ton of aluminum (EPA 1973). Most of this additional aluminum may be produced in the region.

4.4.6 Residential Heat Pumps

Builders may also choose to install heat pumps in energy-efficient homes as a trade-off for less stringent thermal requirements. Residential heat pumps are one of the most energy-efficient space conditioning appliances available, and may cost-effectively contribute to reducing a customer's overall energy requirement. However, heat pumps have been associated with potential environmental impacts: the presence of possibly annoying acoustic emission levels, and potential damage to the earth's ozone layer from fluorocarbon refrigerants.

Noise emission levels from residential heat pumps vary widely among manufacturers, and are dependent on the unit size, fan size and type, compressor noise, and vibration transmission to the heat pump case. While manufacturers try to ensure that their units operate as quietly as possible, heat pumps currently available are generally quite noisy, registering acoustic emission levels from approximately 60 adjusted decibels (dBA) to over 70 dBA at the source. Washington state law, as well as municipal ordinances in several Northwest cities outside of Washington (including Portland), require nighttime noise levels not to exceed 45 dBA at the property line. Fortunately, means are available to effectively reduce heat pump noise to acceptable levels.

One of the simplest and most effective noise control measures is to install the heat pump in a proper location. Placing the heat pump as far as possible from property lines, open windows, and reflective barriers or acoustic enclosures often yields satisfactory noise control. Construction of sound barriers or acoustic enclosures may also be employed to further attenuate noise levels if necessary. Fiberglass insulation wrapped around the heat pump compressor to muffle compressor noise may also be a simple means of reducing heat pump noise. One or more of these methods is usually sufficient to reduce heat pump noise emissions to acceptable levels.

The chlorofluorocarbon (CFC) refrigerants used as the primary heat transfer medium in residential heat pumps are thought to potentially affect the concentration of the earth's protective ozone layer. This theory has been subject to some debate. Even allowing for the potential depletion effect of fluorocarbons on the ozone layer, it is evident that the small amount of additional fluorocarbons that may be released into the atmosphere by additional residential heat pumps will have a negligible effect on ozone depletion in relation to the overall amount of fluorocarbons released each year world-wide from refrigerators, air conditioners, certain types of plastic containers, and industrial processing, as well as the depletion caused by high altitude aircraft. Although alternative heat transfer media are available and may be used in place of fluorocarbon refrigerants, they each have their own inherent disadvantages and are not widely used at present.

The energy conservation benefits available from an increased use of heat pumps have been well established. While some environmental issues have been raised regarding heat pump usage, these appear to be relatively minor concerns at present. Assuming that fluorocarbons do affect the ozone layer, however, BPA is not in a position to regulate fluorocarbon production. The issue is world-wide in scope, and must be addressed on a global scale (Weisburd 1986; Barnett 1986). Bonneville continues to use heat pumps with CFC in its new homes programs but will require more benign heat transfer fluids when they become readily available.

Adverse health effects from heat pump usage should not occur. Under BPA's programs, heat pumps must be installed according to local code requirements, and these are designed to protect public health and should avoid any potential health effects to consumers.

4.5 AVOIDED IMPACTS OF REPLACEMENT ENERGY RESOURCES

If the conservation anticipated from new energy-efficient homes is not realized, and electric demand warrants replacing it, the electricity may need to be obtained from other resources. Both the Council's resource portfolio and BPA's 1986 resource strategy indicated that small hydropower, then cogeneration would be the next resources to be developed, if needed, to meet low load obligations. For medium load obligations BPA will add combustion turbines, and for high load obligations it will add coal plants (Foley and Wilfert 1986). These new resources carry with them environmental impacts. In this section, the impacts of using the four resources to generate electricity instead of acquiring the conservation resource are summarized.

Because it is beyond the scope of this document to project the mix and capacities of generating resources, we assume that each of the replacement resources generate 100% of the energy needed to replace the energy savings of each of the alternatives. Thus, the impacts are scaled or proportioned to match the total regional energy savings anticipated from each of the alternatives. For the Proposed Action Alternative two pathways are shown to bound the range of potential savings from conservation, and thus the impacts of using generation instead of conservation. For this analysis we assume a linear relationship between the generating capacity of replacement resources and the resulting environmental effects. Thus, as resource capacities are multiplied or reduced, their environmental impacts are proportionally increased or decreased. These impacts were calculated by multiplying the numbers in Table 4.18 by the energy savings derived from the No Additional Action and Pathways 4 and 7. The numbers in Table 4.18 represent the impacts per megawatt of generation estimated for a typical 500 MW coal plant (Baechler 1986). So, to calculate impacts avoided from the other pathways, simply multiply the numbers in Table 4.18 by the energy savings for the other pathways (Table 4.13). The avoided environmental impacts of the three representative alternatives are shown in Tables 4.19 through 4.21. These are impacts which do not occur because we obtain the energy from conservation and so do not need the generating resource. These tables indicate the public morbidity from building these plants. We have not estimated health effects from the environmental insults (e.g., 4200 tons of air emissions) resulting from these different plants, primarily because these plants are site-specific; thus, the public health impacts would be determined by where the plant is sited.

TABLE 4.18. Impacts Per Megawatt of Generation for Four Generation Resources

Environmental Impact	Small Hydropower	Cogeneration	Combustion Turbine	Coal-Fired Generator
Description	Run of river or storage-operation	Municipal solid waste fired(a)	Frederickson natural gas-fired turbine and generic, includes transport and extraction effects	Boardman Coal Plant and generic, 70% load factor, includes mining and transport effects
Public mortality(a)	NR	.57(b)	0	.003
Public injuries and morbidity(a)	NR	NR	.003	.026
Occupational safety and health				
mortality	NR	NR	.00003	.00007
injuries	NR	NR	.003	.004
time lost	.007 worker yr	NR	1.49 worker days	4.87 worker days .44 worker days construction
Personnel				
construction (workers/yr)	5.3 (3 yr)	NR	2.65 (4 yr)	NR
operation/maintenance (workers/yr)	.05	NR	.14	.27
Solid waste (tons)	0	(c)	Negligible	.0035 million
Air emissions (tons)	Negligible	55	16.1	35.49
Visibility impairment (km-person-yrs)	NR	NR	111.5	1.21
Water emissions (tons)	Negligible	NR	2.75	NR
Water use (acre-ft unless otherwise noted)	.02 million	.13 million gal.	3.75	4.5 million gal.
Water consumption (acre-ft unless otherwise noted	0	2 million gal.	NR	4.2 million gal.
Fisheries impacts	Yes	NR	NR	Yes
Land use (acres)	67.3	1	.19	1.7
Thermal discharge (Btu)	NR	109 billion	29 billion	42 billion

NR - Not reported in references.

(a) Based on linear dose response model. If EPA Air Quality Standards are assumed to be a threshold, no health effects result.

(b) Mortality/morbidity combined.

(c) Burning solid waste as fuel results in net reduction in solid waste requiring disposal.

Sources: INTASA, Inc. (1981); ECO Northwest, Ltd., Shapiro and Associates, Inc., and Seton, Johnson, and Odell, Inc. (1986); Fassbender, Moore, and Eakin (1982); ECO Northwest (1983, 1984); Battelle Columbus Laboratories (1982); DOE (1983); Baechler (1986).

TABLE 4.19. Total Avoided Impacts of the No Additional Action Alternative(a)

Environmental Impact	Small Hydropower	Cogeneration	Combustion Turbine	Coal-Fired Generator
Description	Run of river or storage-operation	Municipal solid waste fired(b)	Frederickson natural gas-fired turbine and generic, includes transport and extraction effects	Boardman Coal Plant and generic, 70% load factor includes mining and transport effects
Public mortality	NR	77(c)	0	.40
Public injuries and morbidity	NR	NR	.40	3.4
Occupational safety and health				
mortality	NR	NR	.0004	.0094
injuries	NR	NR	.40	.54
time lost	.94 worker yr	NR	195 worker days	653 worker days 60 worker days construction
Personnel				
construction (workers/yr)	710 (3 yr)	NR	355 (4 yr)	NR
operation/maintenance (workers/yr)	6.9	NR	18	37
Solid waste (tons)	0	(d)	Negligible	470,000
Air emissions (tons)	Negligible	7,330	2,176	4,810
Visibility impairment (km-person-yr)	NR	NR	14,888	160
Water emissions (tons)	Negligible	NR	367	NR
Water use (acre-ft unless otherwise noted)	2.6 million	17 million gal.	504	607 million gal.
Water consumption	0	263 million gal.	NR	561 million gal.
Fisheries impacts	Yes	NR	NR	Yes
Land use (acres)	9,050	137	25	229
Thermal discharge (Btu)	NR	14,888 billion	3,894 billion	5,612 billion

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NR - Not reported in references.

(a) Assumed load reduction of 132 average megawatts, based on upper bound estimate.

(b) Based on linear dose response model. If EPA Air Quality Standards are assumed to be a threshold, no health effects result.

(c) Mortality/morbidity combined.

(d) Burning solid waste as fuel results in net reduction in solid waste requiring disposal.

Sources: INTASA, Inc. (1981); ECO Northwest, Ltd., Shapiro and Associates, Inc., and Seton, Johnson, and Odell, Inc. (1986); Fassbender, Moore, and Eakin (1982); ECO Northwest (1983, 1984); Battelle Columbus Laboratories (1982); DOE (1983); Baechler (1986).

TABLE 4.20. Total Avoided Impacts of Pathway 4[a]

Environmental Impact	Small Hydropower	Cogeneration	Combustion Turbine	Coal-Fired Generator
Description	Run of river or storage-operation	Municipal solid waste fired[b]	Frederickson natural gas-fired turbine and generic, includes transport and extraction effects	Boardman Coal Plant and generic, 70% load factor includes mining and transport effects
Public mortality	NR	54[c]	0	.30
Public injuries and morbidity	NR	NR	.30	2.5
Occupational safety and health				
mortality	NR	NR	.0003	.01
injuries	NR	NR	.30	.38
time lost	.68 worker yr	NR	148 worker days	468 worker days 43 worker days
construction				
Personnel				
construction (workers/yr)	505 (3 yr)	NR	246 (4 yr)	NR
operation/maintenance (workers/yr)	4.9	NR	14	27
Solid waste (tons)	0	(d)	Negligible	345,000
Air emissions (tons)	Negligible	5,292	1,477	3,446
Visibility impairment (km-person-yrs)	NR	NR	10,585	117
Water emissions (tons)	Negligible	NR	271	NR
Water use (acre-ft unless otherwise noted)	2.0 million	12 million gal.	357	431 million gal.
Water consumption (acre-ft unless otherwise noted	0	197 million gal.	NR	394 million gal.
Fisheries impacts	Yes	NR	NR	Yes
Land use (acres)	6,523	96	17	160
Thermal discharge (Btu)	NR	10,462 billion	2,831 billion	3,938 billion

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NR - Not reported in references.

(a) Assumed load reduction of 96 total average megawatts of Pathway 4, based on upper bound estimate.

(b) Based on linear dose response model. If EPA Air Quality Standards are assumed to be a threshold, no health effects result.

(c) Mortality/morbidity combined.

(d) Burning solid waste as fuel results in net reduction in solid waste requiring disposal.

Sources: INTASA, Inc. (1981); ECO Northwest, Ltd., Shapiro and Associates, Inc., and Seton, Johnson, and Odell, Inc. (1986); Fassbender, Moore, and Eakin (1982); ECO Northwest (1983, 1984); Battelle Columbus Laboratories (1982); DOE (1983); Baechler (1986).

TABLE 4.21. Total Avoided Impacts of Pathway 7[a]

Environmental Impact	Small Hydropower	Cogeneration	Combustion Turbine	Coal-Fired Generator
Description	Run of river or storage-operation	Municipal solid waste fired[b]	Frederickson natural gas-fired turbine and generic, includes transport and extraction effects	Boardman Coal Plant and generic, 70% load factor, includes mining and transport effects
Public mortality	NR	104[c]	0	.55
Public injuries and morbidity	NR	NR	.55	4.7
Occupational safety and health				
mortality	NR	NR	.01	.01
injuries	NR	NR	.55	.72
time lost	1.3 worker yr	NR	272 worker days	889 worker days 80 worker days
construction				
Personnel				
construction (workers/yr)	963 (3 yr)	NR	481 (4 yr)	NR
operation/maintenance (workers/yr)	9.1	NR	25	48
Solid waste (tons)	0	(d)	Negligible	628,000
Air emissions (tons)	Negligible	9,939	2,930	6,487
Visibility impairment (km-person-yr)	NR	NR	19,879	220
Water emissions (tons)	Negligible	NR	492	NR
Water use (acre-ft unless otherwise noted)	3.7 million	24 million gal.	670	806 million gal.
Water consumption (acre-ft unless otherwise noted	0	366 million gal.	NR	764 million gal.
Fisheries impacts	Yes	NR	NR	Yes
Land use (acres)	12,555	188	35	314
Thermal discharge (Btu)	NR	19,879 billion	5,231 billion	7,638 billion

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NR - Not reported in references.

(a) Assumed load reduction of 181 total megawatts of Pathway 7, based on upper bound estimate.

(b) Based on linear dose response model. If EPA Air Quality Standards are assumed to be a threshold, no health effects result.

(c) Mortality/morbidity combined.

(d) Burning solid waste as fuel results in net reduction in solid waste requiring disposal.

Sources: INTASA, Inc. (1981); ECO Northwest, Ltd., Shapiro and Associates, Inc., and Seton, Johnson, and Odell, Inc. (1986); Fassbender, Moore, and Eakin (1982); ECO Northwest (1983, 1984); Battelle Columbus Laboratories (1982); DOE (1983); Baechler (1986).

4.6 CONSULTATION, REVIEW, AND PERMIT REQUIREMENTS

The federal government and the states have established a number of environmental statutes and regulations that place requirements for review, consultation, and permits on actions proposed by agencies such as BPA. The National Environmental Policy Act (NEPA) and Council on Environmental Quality (CEQ) regulations stipulate that an EIS state how compliance with environmental laws and policies occurs [40 CFR 1502.2(e)]; NEPA also prescribes that review and consultation requirements for a proposed action be integrated into an EIS [40 CFR 1500.4(k)]. In this section, we examine environmental requirements applicable to BPA's proposed New Energy-Efficient Homes Programs and discuss how these requirements will be met. These statutes and regulations are grouped based on the environmental features they are designed to protect.

4.6.1 Fish, Wildlife, and Habitat

Federal policies and procedures for protecting endangered species of fish, wildlife, and plants were established by the Endangered Species Act and regulations issued pursuant to the Act. In addition, the Fish and Wildlife Coordination Act requires federal agencies undertaking projects affecting water resources to consult with the U.S. Fish and Wildlife Service in order to conserve or improve wildlife resources.

The Proposed Action will not affect endangered or threatened species, create land use changes, or affect critical wildlife habitat. The incentives offered under the Proposed Action are not large enough to encourage the construction of new homes that otherwise would not be built. In addition, new homes built under the programs must comply with local building codes and permit requirements. Presumably, building permits are issued only in accordance with local land use plans. The Proposed Action will only encourage energy efficiency and indoor air quality mitigation features in new homes. These actions will not adversely affect endangered or threatened species.

The manufacture, installation, and operation of energy-efficient and mitigation measures proposed in the New Energy-Efficient Homes Programs will not have direct effects on fish and wildlife conservation because the measures do not modify bodies of water. The Proposed Action could have indirect positive effects on fish and wildlife through its electrical energy savings. If these savings reduce the need for hydropower production, such reduction will allow more flexibility for operating Northwest dams to encourage fish and wildlife conservation. This indirect effect on existing hydropower operations cannot now be quantified because the methodology for converting annual energy savings into seasonal and 24-hour cycle savings is not developed. These short-term cycles are important in managing fish resources.

4.6.2 Heritage Conservation

Several federal laws and regulations have been promulgated to protect the nation's historical, cultural, and prehistoric resources. These include the National Historic Preservation Act, the Archeological and Historic Preservation Act, the Archeological Resources Protection Act, the American Indian Religious Freedom Act, the National Natural Landmarks Program, and the World Heritage List. The goal of these acts is to preserve the country's cultural resources and to give Americans an understanding and appreciation of their origins and history.

Potential environmental impacts of the Proposed Action are limited to new homes which must be built in compliance with state and local building codes, land use plans, zones, and programs. Because only new structures are affected, historic buildings will not be affected.

Also, the Proposed Action will not affect other cultural resources. Incentives offered under the Proposed Action are not large enough to encourage the construction of new homes that would not otherwise be built. Therefore, new construction that may affect cultural resources would occur regardless of BPA's undertaking the Proposed Action. In addition, new homes built under the programs must comply with local building codes and permit requirements. Presumably, building permits are issued only in accordance with local land use plans, which protect cultural resources.

4.6.3 Land Use Planning and Critical Resource Protection

- The Coastal Zone Management Act offers grants to states to develop comprehensive, long-range coastal management plans. The plans must identify coastal zone boundaries and define permissible land and water uses within the zone. Within the BPA service area, two states have completed these plans: Oregon and Washington.

- The intent of federal flood plain and wetlands management policy (Executive Orders 11988 and 11990) is to avoid as much as possible adverse impacts associated with developing flood plains or destroying or modifying wetlands.

- The Council on Environmental Quality stated that highly productive farmlands are considered important parts of our national heritage, and efforts should be made to ensure that such farmlands are not irreversibly converted to other uses.

- Many federal laws and policies have been established to protect national recreation resources such as wild and scenic rivers, trails, wilderness, parks, parklands, ecologically critical areas, and areas of critical environmental concern.

Homes resulting from the Proposed Action will be built in compliance with local building codes and permit requirements. Presumably, building permits are issued only in accordance with local land use plans to ensure intergovernmental cooperation and protection for sensitive and critical areas. Furthermore, the incentives offered under the Proposed Action are not large enough to encourage the construction of new homes that would not otherwise be built. Therefore, homes that may be built in protected or sensitive areas would have been built regardless of BPA's New Energy-Efficient Homes Programs. The Proposed Action will affect only the physical character of new homes and will not alter their use as residential structures, affect the number of people that may live in homes, or otherwise change land use patterns. The activities BPA proposes to promote through marketing and financial incentives do not constitute a construction or building program that will directly affect land use plans, coastal zones, flood plains, wetlands, farmlands, recreation resources, or other protected or critical areas.

4.6.4 Permits

- Pursuant to the Rivers and Harbors Appropriation Act of 1899, Section 10, the U.S. Army Corps of Engineers issues permits for various types of activities that occur in the waters of the United States.
- The Federal Water Pollution Control Act (Clean Water Act) requires the Army Corps of Engineers to issue "Section 404" permits for discharges of dredged or fill materials into waters of the United States.
- The Federal Land Policy and Management Act of 1976 authorizes the Secretaries of Interior and Agriculture to grant utility and other rights-of-way on federal lands under their jurisdictions.

Because the Proposed Action does not entail activities that require any of the above permits, these regulations are not relevant to BPA's New Energy-Efficient Homes Programs.

4.6.5 Intergovernmental Cooperation

The Intergovernmental Cooperation Act of 1968 and other federal laws and regulations form a national policy for intergovernmental coordination and cooperation and require consistency to the maximum extent practicable between federal aid programs and regional, state, and local planning.

Homes resulting from the Proposed Action will be built in compliance with local building codes and permit requirements. Presumably, building permits are issued only in accordance with local land use plans to ensure intergovernmental cooperation and protection for sensitive and critical areas.

4.6.6 Pollution Control

- The Clean Air Act sets the basic framework for federal, state, and local air quality management programs.
- The Clean Water Act sets forth the national strategy for controlling water pollution.

- The Resource Conservation and Recovery Act establishes national policies and programs for solid and hazardous waste management.
- The Safe Drinking Water Act establishes the national program for protecting drinking water supplied by municipal and industrial water suppliers.
- The Noise Control Act of 1972 established a federal policy and various programs to control noise detrimental to public health and welfare.
- The Federal Insecticide, Fungicide, and Rodenticide Act established procedures for the registration, classification, and regulation of herbicides and other pesticides.
- The Toxic Substances Control Act empowers EPA to control production and use of toxic substances.

Indoor air quality is not regulated by the Clean Air Act and related state and local implementing regulations in the region. However, the manufacture of materials for energy conservation and indoor air quality mitigation could lead to emissions of air pollutants and would be regulated by clean air mandates. BPA does not anticipate that manufacture of these materials will generate higher levels of impacts than would occur under the No Action Alternative. The Proposed Action would not necessitate construction of new manufacturing plants, so there would be no new sources of air pollution attributable to BPA's Proposed Action. Existing manufacturing plants must comply with ambient air quality standards in their localities.

The Proposed Action would not lead to discharges of oil or hazardous waste into U.S. navigable waters or adjoining shorelines. Therefore, the program is not affected by the Clean Water Act or related federal regulations.

The Proposed Action involves only materials commonly used in construction and renovation of buildings and will not entail the generation, transportation, treatment, storage, or disposal of hazardous waste. Procurement contracts required by the Proposed Action will not exclude the use of recycled material, nor will the program affect other aspects of solid waste management, including source separation and recycling of products, or storage, transport, and disposal of solid waste. Because of these factors, the Proposed Action is not affected by federal legislation and related regulation about disposal of solid and hazardous wastes.

Drinking water standards will not affect the installation of energy conservation and IAQ mitigation features in new homes. Further, these features will not be located where they will affect ground water. No new public water systems will be built as part of the Proposed Action.

Installation of energy conservation and indoor air quality mitigation features will not emit sounds affecting noise levels, so state and local standards and regulations governing environmental noise will not affect the Proposed Action.

The Proposed Action will not require the purchase, use, storage, or disposal of any insecticides, fungicides, or rodenticides. Further, none of the efficiency or IAQ mitigation features under the Proposed Action will require the production, manufacture, or distribution of substances listed under the Toxic Substances Control Act, including polychlorinated biphenyls (PCBs).

LIST OF PREPARERS

5.0 LIST OF PREPARERS

5.1 BONNEVILLE POWER ADMINISTRATION

Charles C. Alton (B.S. Sociology, Certificate Urban Studies, M.S. Public Administration) is the Environmental Coordinator for the Office of Conservation and Power Resources. Has extensive experience in environmental impact studies for wide range of electric utility industry activities. Contribution: Environmental compliance and oversite and Technical Review.

Laura J. Bibo (B.A., M.A. Economics) is a Public Utilities Specialist in the Division of Power Forecasting primarily involved in preparing residential energy forecasts. Contribution: Technical Review and housing forecast data.

Jeffrey P. Harris (B.S. Electrical Engineering, M.S. Mechanical Engineering) is an engineer responsible for various thermal energy analysis and simulation studies related to the BPA New Homes Program. Contributions: Technical Appendix on Estimation of Ventilation Rates for for Ventilation Strategies in New Residences and Technical Review.

Ruth L. Love (B.A., M.A., Ph.D. Sociology) is the environmental coordinator for the Office of Conservation. She has considerable experience in assessing the social effects of proposed water resources development projects. Contribution: BPA Project Manager and Technical Review.

Katherine S. Pierce (B.A. Biology, B.S. Forestry and Wildlife Ecology, M.F. Forestry) works in the Environmental Manager's Office on analysis and formulation of Bonneville's policies under the National Environmental Policy Act (NEPA). Contribution: Liaison with the U.S. Department of Energy and NEPA compliance review.

Suzanne S. Rowan (B.A. Architecture, M.S. Architecture/Structural Engineering) is an architect responsible for technical and environmental support of the BPA New Homes Programs. Contribution: Technical Review and Project Manager for Final EIS.

Philip W. Thor (B.S. Mechanical Engineering) has participated over the past 5 years in the development of BPA's research efforts on indoor air quality and the effects of weatherization. He has been a project manager on several of the projects investigating the measurement and mitigation of indoor air pollutants. Contribution: Technical Review.

5.2 PACIFIC NORTHWEST LABORATORY

Michael C. Baechler (B.A. Environmental Studies) has participated or directed numerous projects involving the assessment of indoor air quality impacts. Contributions: Project co-manager and principal DEIS author.

Judith A. Bamberger (B.S. Physics and Chemistry, M.S. Mechanical Engineering) has extensive research experience in the areas of aerosol and air pollution control, heat transfer and thermal hydraulics. She is a registered professional engineer (mechanical) in the State of Washington. Contribution: Technical appendix on Mitigation Technologies and Regional Health Impacts.

Kristi H. Branch (B.A. Chemistry/English, M.A. Education, Ed.D Education [pending]) has extensive research experience in social impact assessment and community development. Contribution: Technical appendix on Economic and Social Effects of the Model Conservation Standards.

Jenifer W. Callaway (B.A. Political Sciences/Life Sciences, M.S. Environmental Planning/Public Affairs) specializes in environmental and regulatory assessments of energy development projects. Contribution: Technical appendixes on New Homes Conservation Resource and Economic and Social Effects of the Model Conservation Standards.

Fred T. Cross (B.S. Engineering Physics, M.S. Radiation Biology, Ph.D. Biophysics) has expertise in radiation dosimetry and specializes in studies involving specific biological effects of daily exposures to known levels of pathogenic uranium mine air contaminants, such as radon, using both large and small experimental animal models of human respiratory system disease. Contribution: Technical appendix on Health Effects.

Andrea J. Currie (B.S. Experimental Psychology, M.Ed. Guidance/Counseling) is an experienced technical editor/writer with a background in editorial management. Contribution: Editor for DEIS and participating editor for supporting technical appendixes.

M. Kevin Drost (B.S., M.S., and Ph.D. Mechanical Engineering) is a Senior Research Engineer with extensive research experience in the fields of energy conversion, heat transfer, and thermodynamics. Contribution: Technical appendix on Mitigation Technologies.

Jeffrey E. Englin (B.S., M.A., and Ph.D. Economics) specializes in cost benefit analysis and economic issues relating to environmental problems. Contribution: Technical appendix on Regional Expenditures.

Lorraine O. Foley (B.A., M.A. English Literature) has participated in a number of projects in the area of building energy conservation and related policy issues. Contribution: Project co-manager and principal author of Final EIS, Technical appendix on BPA's Resource Strategy and contributor to DEIS.

Paul L. Hendrickson (B.S. Chemical Engineering, M.S. Management Sciences, J.D.) specializes in legal and policy analysis research related to energy and environmental issues. He is a licensed attorney in the state of Washington. Contribution: Technical appendix on Economic and Social Effects of the Model Conservation Standards.

Benjamin M. Johnson (B.S. and Ph.D. Chemical Engineering) specializes in chemical and mechanical engineering research management including direction of development projects related to energy production, utilization, and conservation. He is a registered professional engineer. Contribution: Technical appendix on Mitigation Technologies.

Audrey J. Lyke (B.A. Economics) has been involved in the analysis of energy demand data, focusing on potential displacement as the result of proposed conservation policies. Contribution: Technical appendix on New Homes Conservation Resource.

Peter J. Mellinger (B.S. Biology, M.S. Radiation Biology, Ph.D. Marine Radioecology) specializes in the assessment of the effects of radiological and carcinogenic contaminants on human health and safety. Contribution: Technical appendix on Health Effects.

Andrew K. Nicholls (B.A. English/Economics, M.A. Economics) has been involved in the analysis of energy use data, focusing on energy use trends. Contribution: Technical appendix on Economic and Social Effects of the Model Conservation Standards.

Georganne P. O'Connor (B.A. Spanish) has several years' editing/writing experience in government and private industry. She is a graduate of the Book and Magazine Publishing Program of the George Washington University. Contribution: supporting editor for the DEIS and technical appendixes.

William F. Sandusky (B.S. Space Technology, M.S. Meteorology) has extensive experience in modeling pollutant transport and dispersion over various time and space scales for radiological and air quality assessments. He also has done considerable work in measuring meteorological parameters and computer simulation techniques. Contributions: PNL Project Manager, Regional Health Effects and Risk Assessment.

Steven A. Shankle (B.A. Economics) is involved in various economic analysis studies with emphasis on various computer data processing techniques. Contribution: Technical appendix on Economic and Social Effects of the Model Conservation Standards.

Dartha R. Simpson (B.A. Education/Language Arts) is a technical editor/writer with a background in teaching, editing, and writing. Contribution: Participating editor for technical appendixes.

K. Ruth Taylor (B.A. Architecture) specializes in building energy analysis and using simulation techniques to determine building thermal efficiency. Contribution: Technical appendix on New Homes Conservation Resource.

Alfred P. Wehner (Sc.D. Medical Microbiology, D.D.S., Candidate Med.) is a biomedical scientist involved in various elements of inhalation toxicological research. Recently his research has focused on human health effects resulting from various indoor pollutant concentration level. Contribution: Technical appendix on Health Effects.

5.3 NATIONAL CENTERS FOR DISEASE CONTROL (ATLANTA)

Lowell E. Sever (B.A., M.A. Anthropology, Ph.D. Biological Anthropology) is an epidemiologist with experience in occupational and environmental epidemilology. His professional activities have included the application of epidemilology, surveillance, and risk assessment methods to the identification and evaluation of health hazards. Contribution: Technical appendix on Health Effects.

LIST OF PERSONS TO WHOM COPIES OF THE EIS ARE SENT

6.0 LIST OF AGENCIES, ORGANIZATIONS, AND PERSONS TO WHOM COPIES OF THE STATEMENT ARE SENT(a)

FEDERAL AGENCIES

Advisory Council on Historic Preservation

Consumer Product Safety Commission

Tennessee Valley Authority, Chattanooga, TN; Muscle Shoals, AL

US Army Corps of Engineers
  Environmental Engineer
  Flood Control and Hydro Planning Section
  HQDA Daen CWR P Makinen
  North Pacific Division
  Portland District
  Seattle District, Chief Environmental Resources

US Attorneys Office

US Department of Agriculture
  Cooperative Extension Service, AK
  Forest Service, Region 1
  Forest Service, Region 6
  Missouri Cooperative Extension Service
  Office of the Secretary
  Pacific Northwest Forest ane Range Experiment Station
  Rural Electrification Administration
  Soil Conservation Service

US Department of Commerce
  Ecology and Conservation Division
  National Oceanic and Atmospheric Administration
  Office of the Secretary

(a) We are sending a summary of the EIS to a large number of interested parties whose names do not appear on this list. They include businesses, individuals, universities, and local governmental offices.

US Department of Energy
  Federal Energy Regulatory Commission
  Intergovernmental Affairs CP-23
  Oak Ridge National Laboratory
  Office of Communication
  Office of Energy Research
  Puget Sound Area Conservation OSCB
  Richland Operations Office, Chief Counsel
  Weatherization Assessment Program
  Western Area Power Administration

US Department of Health and Human Services
  Centers for Disease Control
  Food and Drug Administration, National Center for Devices and Radiological Health
  Office of the Secretary
  Public Health Service, Environmental Health Services Division
  Regional Office, Denver, CO
  Regional Office, Seattle, WA

US Department of Housing and Urban Development
  Seattle Regional Office

US Department of the Interior
  Bureau of Indian Affairs, Portland, OR
  Bureau of Indian Affairs, Western Washington Agency
  Bureau of Land Management, Planning and Environmental Coord. Staff
  Bureau of Reclamation, Pacific Northwest Region
  Geological Survey
  Office of Environmental Project Review
  Regional Environmental Officer

US Environmental Protection Agency
  Air and Energy Engineering Research Lab, Research Triangle Park
  Air Programs MS 532,
  Environmental Criteria and Assessment Office
  Environmental Monitoring Systems
  Gas, Kinetics and Photochemistry Branch
  Health Effects Research
  Indoor Air Quality Interagency Research Group
  Office of Air Quality Planning and Standards
  Office of Health Research
  Office of Radiation Programs, Criteria and Standards Division
  Regional Director, Region X

US Naval Radio Station T
US Naval Submarine Base Bangor

US Small Business Administration

STATE HISTORIC PRESERVATION OFFICES

Idaho Historical Society
Montana Historical Society
Nevada Division of Historic Preservation and Archeology
Oregon State Parks Administration
State of California Historic Preservation
Utah State Historical Society
Washington Office of Archeology and Historic Preservation
Wyoming Recreation Commission

STATE GOVERNORS

Honorable George Deukmejian, Governor of California
Honorable Cecil Andrus, Governor of Idaho
Honorable Ted Schwinden, Governor of Montana
Honorable Neil Goldschmidt, Governor of Oregon
Honorable Booth Gardner, Governor of Washington
Honorable Mike Sullivan, Governor of Wyoming

STATE AGENCIES

California

California Association of Counties
California Energy Resource Conservation & Development
California Energy Commission
Clearinghouse
League of California Cities
Public Health Unit Air Quality
Public Utilities Commission
Toxic Air Pollutants Branch, Air Resources Board

Colorado

Office of Energy

Idaho

Association of Idaho Cities
Department of Commerce
Department of Health and Welfare, Environmental Services, Division of Health, Radiation Control
Department of Water Resources
Division of Economic and Community Affairs
Idaho Association of Counties
Office of Energy
Office of Governor, Division of Financial Management

Public Utilities Commission
Public Utilities Commission, Chief Counsel

Montana

Department of Natural Resources and Conservation
District XI Human Resources Couocil
Division of Energy
Energy Facility Siting Bureau
Environmental Quality Council
Intergovernmental Review Clearinghouse
Local Government Energy Office
Montana Association of Counties
Montana League of Cities & Towns
Office of the Governor
Public Service Commission

Nevada

Colorado River Commission
Department of Social and Health
Nevada League of Cities
Office of Community Services
Public Service Commission

Oregon

Accreditation B, Fire Marshall
Association of Oregon Counties
Bureau of Governmental Research and Community Services
Conservation Division, Local Government Programs
Department of Commerce, Building Codes Division, Housing Council
Department of Energy
Department of Energy, New Construction Program, Div. of Resource Dev.
Department of Environmental Quality
Department of Land Conservation & Development
Division of Health
Intergovernmental Relations Division
League of Oregon Cities
Oregon PUD Association
Parks and Recreation Division, Design Unit Supervisor
Public Utility Commission

Utah

Department of Health
Energy Office
Office of the Governor, Planning Coordinator

Public Service Commission
Utah Association of Counties
Utah League of Cities and Towns

Washington

Department of Ecology, NEPA Coordinator
Department of Wildlife
Department of Social and Health Services
Energy Facility Siting Council
Energy Office
Office of Radiation Protection
Office of the Governor
Planning and Community Affairs Agency
State Building Code Council, Department of Community Development
Utilities and Transportation Commission
Washington Association of Cities
Washington Association of Counties

Wyoming

Energy Conservation Office
Environmental Health Program
Public Service Commission
Wyoming Association of Municipalities
Economic Development and Stabilization

Others

State of Minnesota
    Department of Energy and Econ Div
    Department of Health
    Department of Trade and Economic Development

State of New York
    Department of Environmental Conservation
    Department of Health
    Department of Public Service
    Energy Office

State of Wisconsin
    Department of Industry, Labor and Human Relations
    Public Service Commission

STATE LEGISLATIVE

House Committee on Agricultural Affairs, Idaho
House Committee on Agriculture, Livestock and Irrigation, Montana
House Committee on Agriculture, Washington
House Committee on Business and Labor, Montana
House Committee on Business, Idaho
House Committee on Commerce and Labor, Washington
House Committee on Energy and Utilities, Washington
House Committee on Environmental Affairs, Washington
House Committee on Environment and Energy, Oregon
House Committee on Fish and Game, Montana
House Committee on Local Government, Idaho
House Committee on Local Government, Montana
House Committee on Local Government, Washington
House Committee on Resources and Conservation, Idaho
House Committee on Trade and Economic Development, Oregon
House Committee on Trade and Economic Development, Washington
House of Representatives, Boyd, Geddes, Meibaur, Idaho
House of Representatives, Iverson, Quilici, Montana
House of Representatives, Cease, Montgomery, Oregon
House of Representatives District Office
Legislative Assembly, Oregon
Legislative Council, Idaho
Senate Committee on Agricultural Affairs, Idaho
Senate Committee on Agriculture, Livestock and Irrigation, Montana
Senate Committee on Agriculture, Washington
Senate Committee on Commerce and Labor, Idaho
Senate Committee on Commerce and Labor, Washington
Senate Committee on Fish and Game, Montana
Senate Committee on Local Government, Montana
Senate Committee on Natural Resources, Washington
Senate Committee on Parks and Ecology, Washington
Senate Committee on Public Health, Welfare and Safety, Montana
Senate Committee on Resources and Environment, Idaho
Senate Committee on Water Policy, Oregon
Senate Energy and Utilities Committee, Washington
Senate Office, Oregon
Senate, Watkins, Idaho

NORTHWEST POWER PLANNING COUNCIL

LOCAL AGENCIES AND CLEARINGHOUSES

Idaho

City of Bonners Ferry
City of Idaho Falls
City of Lewiston
City of Moscow, Energy Advisor

Areawide

Clearwater Economic Development Association
County of Bonneville
County of Clearwater
East Central Idaho Planning and Development Association
Nez Perce Tribal Executive Comm.
Panhandle Area Council
Region IV Development Association
Southeast Idaho Council of Governments

Montana

City of Helena, Commissioner Wordal
City of Kalispell, Councilman Palmer
City of Missoula, Councilman Rice
City of Polson, Commissioner Hutchin

Areawide

Butte Silver Bow Planning Board
City/County of Bozeman, Planning Board
City/County of Kalispell, Planning Board
County of Granite, Planning Office
County of Jefferson, Commissioner Schmitz
County of Missoula, Commissioner Schwartz, Commissioner Dussault
Flathead Areawide Planning Organization
Northern Plains Resource Council

Oregon

City of Milton-Freewater
City of Portland, Deputy City Attorney, Intergovernmental Affairs
County of Clackamas
County of Klamath
County of Linn, Planning and Building Department, Commissioner Stephani
County of Multnomah, Intergovernmental Affairs
County of Washington
Lane Regional Air Pollution Authority

Areawide

Blue Mountain Intergovernmental Council
Central Oregon Intergovernmental Council
Clatsop Tillamook Intergovernmental Council
Coos Curry Council of Governments
East Central Oregon Association of Counties
IDA-ORE Planning and Development Association, Inc.
Lane Council of Governments
Metropolitan Service District, Portland
Mid Columbia Council of Governments
Mid Willamette Valley Council of Governments
Oregon District 4 Council of Governments
Rogue Valley Council of Governments
Umpqua Regional Council of Governments

Washington

City of Everett
City of Tacoma, Energy Coordinator
County of Chelan, Commissioner Young
County of Skagit, Community Action Agency, Community Development
Southwest Washington Health District

Areawide

Adams County Planning Department
Asotin County Planning Commission
Benton Franklin Governmental Conference
Big Bend Economic Development Council
Chelan County Governmental Conference
Clallam County Intergovernmental Clearinghouse
Cowlitz Wahkiakum Governmental Conference
Douglas County Regional Planning Council
Grays Harbor Regional Planning Commission
Island County Planning Department
Intergovernmental Resource Center, Clark County
Jefferson Port Townsend Regional Council
Kittitas County Planning Office
Klickitat Regional Council
Lewis County Planning Department
Mason Regional Planning Council
Okanogan County Planning Department
Pacific County Regional Planning Council
Puget Sound Council of Governments
San Juan County Planning Department
Skagit Council of Governments
Skamania Regional Planning Council
Spokane Regional Council
Thurston Regional Planning Council

TRICO Economic Development District
Walla Walla County Regional Planning
Whatcom County Council of Governments
Whitman County Regional Planning Council
Yakima Valley Conference of Governments

LIBRARIES

Boise Public Library
Boise State University Library
Butte Silver Bow Public Library
California State Library
California State University at Sacramento
Caroline County Public Library
Carroll College Library
Central Washington University Library
College of Southern Idaho Library
Colorado State U. Library
Eastern Montana College Library
Eastern Oregon College
Eastern Washington University, JFK Library
Ellensburg Public Library
Everett Community College Library
Everett Public Library
Evergreen State College
Fort Vancouver Regional Library
Gonzaga University School of Law Library
Huxley College Environmental Library
Idaho State Library
Idaho State University Library
Lewis and Clark College Watzek Library
Library Association of Portland
Linfield College Northrup Library
Montana College of Mineral Science and Technology Library
Mid Columbia Library
Montana Historical Society Library
Montana State Library
Montana State University Renne Library, Documents Librarian
Northern Montana College Library
Northwestern School of Law Boley Law Library
Oregon College of Education Library
Oregon Institute of Technology Learning and Resources Center
Oregon State Library
Oregon State University Library
Pacific University Scott Library
Pierce County Rural Library District
Port Angeles Public Library
Portland State University Library
Reed College Library
Ricks College McKay Library

Seattle Public Library
Southern Oregon State College Library
Spokane Public Library
State of Washington Energy Office
Tacoma Public Library
University of Idaho College of Law Library
University of Idaho Library
University of Montana Environmental Library
University of Montana Mansfield Library
University of Oregon Law Library
University of Oregon Library
University of Puget Sound Law Library
University of Puget Sound Collins Memorial Library
University of Washington Gallagher Law Library
University of Washington,Governmental
US Court of Appeals 9th Circuit Library
US Department of Energy Library FOI, Washington, DC
Washington State Library
Washington State University Library
Western Oregon State College Library
Western Washington University Wilson Library
Whitman College Penrose Memorial Library
Willamette University College of Law Library
Willamette University Main Library

UTILITIES

Alaska Electric Light and Power Co.
B C Hydro, Energy Management
Benton County PUD
Benton Rural Electric Asn.
Big Bend Electric Coop, Inc.
Bountiful City Light and Power
Bureau of Public Utilities
Cascade Natural Gas Corp.
Central Lincoln PUD
Central Oregon PUD
City of Ashland, OR
City of Bonners Ferry
City of Drain, OR
City of Forest Grove, OR
City of Idaho Falls, ID
City of Los Angeles, CA
City of McMinnville, OR
City of Monmouth, OR
City of Richland, WA
City of Roseville, CA
City of Rupert, ID
City of Tacoma, WA
Clark County PUD
Clark County PUD Owners Association

Clatskanie PUD
Clearwater Power Co.
Columbia Gas System
Columbia River PUD
Consolidated Edison Company of New York, Inc.
Consumers Power, Inc.
County of Grays Harbor, WA
County of Island, WA
Cowlitz County PUD No. 1
Direct Service Industries, Inc.
East End Mutual Electric Co. Ltd.
Emerald PUD
Eugene Water and Electric
Fall River Rural Electric Coop, Inc.
Flathead Electric Coop, Inc.
Franklin County PUD
Glacier Electric Coop, Inc.
Grant County PUD
Grays Harbor County PUD No. 1
Hartco Electric
High Plains Energy
Hood River Electric Cooperative
Idaho Cooperative Utilities Association
Idaho Power Company
Industrial Customers of Northwest Utilities
Inland Power and Light Company
Intermountain Gas Company
Intermountain Power Agency
Jacksonville Electric Authority
Jersey Central Power and Light Company
Kootenai Electric Cooperative, Inc.
Lane Electric Cooperative, Inc.
Lincoln Electric Cooperative, Inc.
Lost River Electric Coop, Inc.
Lower Valley Power and Light, Inc.
Mason County PUD No. 1
Mason County PUD No. 3
McMinnville Water and Light
Midstate Electric Coop, Inc.
Missoula Electric Coop, Inc.
Montana Light and Power Company
Montana Power Co.
Northern Lights, Inc.
Northern Wasco County PUD
Northwest Natural Gas Company
Northwest Utilities, Consultant
Northwest Power Planning Coordination Group
Ohop Mutual Light Co.
Ontario Hydro
Oregon Municipal Utilities
Pacific County PUD No. 2
Pacific Gas and Electric Company

Pacific Northwest Generating Company
Pacific Power and Light Company
Parkland Light and Water Company
Pasadena Water and Power
Pend Oreille County PUD No. 1
Peninsula Light Company
Pennsylvania Power and Light
Pennwalt Corporation
Philadelphia Electric Company
Portland General Electric Company
Prairie Power Cooperative, Inc.
Puget Sound Power and Light Company
Raft River Rural Electric Coop
Ravalli County Electric Coop, Inc.
Riverside Electric Coop
Rural Electric Company
Salem Electric
Salmon River Electric Coop, Inc.
Seattle City Power and Light
Sierra Pacific Power Company
Skamania County PUD No. 1
Snohomish County PUD No. 1
Southern California Edison Company
Southern California Gas Company
Surprise Valley Electrification Corp.
Tillamook County PUD
Toledo Edison Company
Town of Steilacoom, WA
United Power Association
Utah Power and Light Company
Vigilante Electric Coop, Inc.
Wahkiakum County PUD
Wasco Electric Coop, Inc.
Washington Natural Gas Company
Washington PUDs Association
Washington Water Power Company
Wells Rural Electric Company
West Kootenay Power and Light Company
Wisconsin Electric Power Company
Woodburn Electric

INTEREST GROUPS

Affiliated Tribes of Northwest Indians
Alliance to Save Energy
American Council for an Energy Efficient Economy
American Gas Association
American Lung Association
American Plywood Association
Amity Foundation
CH2M Hill

Colville Indian Tribe
Clearing Up Newsletter
Committee for Fair Rates
Common Cause
Communities United Responsible Energy
Coop Power Association
Cost Consulting
Council of Energy Resource Tribes
ECO Systems
Elder Citizens Coalition of Washington
Energy Business Association
Environmental Defense Fund
Eugene Future Power Committee
Fair Electric Rates Now
Forelaws on Board
Graypanthers of Portland
Greenpeace Foundation
Harza Engineering Company
Idaho Consumers Affairs Inc.
Idaho Wildlife Federation Consumer Affairs
International Brotherhood of Electrical Workers
Klamath Solar Association
League of Publicly Owned Electric Utilities of Oregon
League of Women Voters of Kitsap
League of Women Voters, ID
League of Women Voters, OR
League of Women Voters, WA
League of Women Voters of Oregon
League of Women Voters of Portland
Lindsay, Hart, Neil and Weigler
Methven and Associates
Mt. Baker Watershed Protection Association
Municipal Research and Services Center
National Association of Homebuilders
National Cancer Institute
National Council for Clean Indoor Air
National Electrical Mfg. Association
National Institute of Building Sciences
National Research Council of Canada
Natural Resources Defense Council
Northwest Conservation Act Coalition
Northwest Conservation Act Report
Northwest Environmental Defense Center
Nureen, John and Company
Oil Heat Institute of Oregon
Oregon Consumer League
Oregon Ecumenical Center for Environmental Action
Oregon Extension Master Conservers
Oregon Fair Share
Oregon Lung Association
Oregon Manufactured Housing Association
Oregon Society for Hosp Engineering

Oregon State Homebuilders Association
OSPRIG
Oregon Wheat Growers League
Pacific Northwest Utilities Conference Committee
Pierce County Action
Pierce County Pomona Grange No 16
Plan
Public Power Council
Quilici Glass
Rockey Marsh Public Relations
Seattle King County Bar Association
Seattle Master Builders Association
Shannon Davis Research Group
Sierra Club
State of Idaho Grange
State of Washington Grange
State of Oregon Grange
Structural Engineers Association of Oregon
Sunergy
Tri City Industrial Development Council
Washington Association of Realtors
Washington Environmental Council
Washington State Grange
Weather or Not
Western Forestry and Conservation Association
Yakima Solar Energy Association

COMMENTORS

Air X Change
Max Bader
Cavalier Corporation
Compliance Systems Publications, Inc.
Ecotope, Inc.

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7.0 REFERENCES

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GLOSSARY AND ACRONYMS

8.0 GLOSSARY AND LIST OF ABBREVIATIONS AND ACRONYMS

8.1 DEFINITION OF TERMS

active ventilation: The movement of air into and out of a building, using mechanical devices.

air-change rate: Amount of air that flows into or out of a building in a specified amount of time.

air exchange: The total movement of air into and out of a building by passive (natural) and active (mechanical) ventilation.

balanced: A mechanical ventilation system is said to be balanced when it actively draws in as much air as it supplies, thereby causing no pressure difference between indoors and outdoors.

benzo[a]pyrene (BaP): A tarry, organic material that is a by-product of incomplete combustion. BaP has been shown to induce cancer in animals.

carbon monoxide: A colorless, odorless gas that comes from incomplete combustion.

carcinogen: A substance capable of causing cancer.

concentration: Amount of a pollutant in a given volume of air.

contaminant: Substance in the air that is not normally present or that is present in greater-than-normal concentration.

degree day, heating: A unit, based on temperature difference and time, used to estimate fuel consumption and specify nominal heating load of a building in winter. If the average of a day's high and low temperature extremes is at or above 65°F, the degree-days for that day are taken to be zero; otherwise, they are equal to the difference between the average and 65°F. Note that a larger number of degree-days implies colder temperatures.

diffusion: Spontaneous scattering of particles and molecules throughout the air from areas of high concentration to areas of low concentration.

emission: A discharge of pollutants into the atmosphere.

emission rate: Amount of a contaminant released into the air by a source in a specified amount of time.

Environmental Impact Statement (EIS): A document prepared by a federal agency assessing the environmental effects of its proposals for legislation and/or other major actions significantly affecting the quality of the human environment. Environmental Impact Statements are used as tools for decision making and are required by the National Environmental Policy Act of 1969.

equivalent leakage area: A quantity roughly equivalent to the sum of the areas of all the openings in the building shell through which air is able to pass.

fan pressurization test: Also referred to as a "blower door test" is a technique used to measure air leakage rates of structures by using a fan to pressurize or depressurize a structure to a given level. The pressure drop is then measured between indoors and outdoors. This method measures only the contribution made to ventilation by air leakage or infiltration.

formaldehyde: An organic chemical widely used to bond material. Formaldehyde-based glues and binders are widely used in products such as plywood, particle board, and furniture.

guidelines: Criteria recommended by government agencies, professional organizations, or other groups. Guidelines are not legally binding.

house tightening: The process of sealing cracks, joints, and other nonintentional paths by which outside air may enter a residence.

levelized cost: The present value of a resource's cost (including capital, interest, and operating costs) split into a series of equal annual payments and divided by annual kilowatt-hours saved or produced. Unlike installed cost, levelized costs permit comparisons of resources with different lifetimes and generating capabilities.

Lifetime Cancer Rate: The number of cancers estimated to occur per 100,000 persons over the course of a given period of time used to define a lifetime.

lifetime risk: Risk resulting from lifetime exposure.

low-fuming: Products made with formaldehyde resins designed to release less amounts of formaldehyde gas than otherwise comparable products.

manufactured home: A structure, such as a mobile home, that is transportable in one or more sections and that is built on a permanent chassis and designed to be used as a dwelling, with or without a permanent foundation.

multifamily structure: A structure consisting of more than four residential units.

nitrogen dioxide: A gas formed during combustion.

passive ventilation: The movement of air into and out of a building through and around cracks and joints and windows and doors.

perfluorocarbon tracer gas test (PFT): The measurement of air exchange rates in a building by mixing a tracer gas throughout the ventilated space and monitoring concentration over time. This method accounts for contributions to ventilation of air leakage, occupant behavior and mechanical devices.

pollutant: Contaminant present in a concentration high enough to cause adverse effects to health or environment.

R-value: Refers to a material's ability to resist heat flow. The higher the R-value the better the insulating qualities. R-values are inversely proportional to U-values.

radon: A colorless, radioactive gas formed by the disintegration of radium.

radon progeny: Products of the radioactive decay of radon. The decay of radon leaves a charged metal atom that can attach to dust. Both attached and unattached particles can be inhaled and can lodge in the lung. The alpha and beta particles emitted by the radon progeny can damage lung tissue.

respirable suspended particles (RSP): Particles less than 3.5 microns in diameter. When inhaled, RSP tend to be carried into the deepest part of the lung.

risk factor: Excess risk per unit of dose at a specified dose level.

single-family dwelling: A structure consisting of four or fewer residential units.

slab-on-grade: A residence is said to be built "slab-on-grade" when it is built on a concrete slab that is at or near the prevailing ground surface.

source: Object or process that releases contaminants into the air.

standards: Criteria enacted by statute or regulation that are legally binding.

statistically significant difference: How closely the measure obtained from a particular sample approximates the true measure. (The true measure is the value you would get if you used a large number of cases or all the cases in the population you were studying.

UA: U-value for the entire area of a structure

urea-formaldehyde foam insulation: A form of insulation blown into walls of homes, primarily during the 1970s.

unbalanced: A mechanical ventilation system is said to be unbalanced when it moves air predominantly in only one direction, either into or out of a structure, resulting in a pressure difference between indoors and outdoors.

U-value: Refers to a material's ability to conduct heat, the lower the U-value the better the insulating qualities. U-values are inversely proportional to R-values.

ventilation: The movement of air into and out of a building.

whole-house ventilation: An active ventilation system designed to move and circulate air into and out of an entire residence.

8.2 ABBREVIATIONS AND ACRONYMS

AAHX: air-to-air heat exchanger

ACH: air changes per hour

ASHRAE: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

BaP: benzo[a]pyrene

BPA: Bonneville Power Administration

Btu: British thermal unit

CFM: cubic feet per minute

CFR: Code of Federal Regulations

CIIT: Chemical Industry Institute of Toxicology

the Council: Northwest Power Planning Council

CPSC: Consumer Products Safety Commission

CRA: Charles River Associates

DOE: U.S. Department of Energy

EIS: environmental impact statement

ELA: equivalent leakage area

EPA: U.S. Environmental Protection Agency

FEIS: Final Environmental Impact Statement

HCHO: formaldehyde

HRV: heat recovery

HUD: U.S. Department of Housing and Urban Development

IAQ: indoor air quality

ICRP: International Commission on Radiological Protection

LCC: life-cycle cost

MCS: Model Conservation Standards

MV: mechanical ventilation

MVHR: mechanical ventilation with heat recovery

NCAC: Northwest Conservation Act Coalition

NCRP: National Commission on Radiological Protection

NEPA: National Environmental Policy Act of 1969

NRECA: National Rural Electric Cooperative Association

NWPPC: Northwest Power Planning Council

OSHA: Occupational Safety and Health Administration

PCBs: polychlorinated byphenyls

pCi/l: picocuries per liter

PFT: perfluorocarbon tracer gas

the Plan: Northwest Conservation and Electric Power Plan

PNL: Pacific Northwest Laboratory

ppm: parts per million, a unit of concentration. When applied to air pollutants, ppm refers to units of a pollutant per million units of air.

RH: relative humidity

RSP: respirable suspended particulates

RSDP: Residential Standards Demonstration Program

SGC: Super GOOD CENTS Program

TSP: total suspended particulates

UBC: Uniform Building Code

WHB: whole-house balanced

WL: working levels

WLM: working level months

: in Appendix C, an "" is used as a multiplication symbol