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DE91 000806

VENTILATION MEASUREMENTS IN
ENERGY-EFFICIENT MULTIFAMILY
DWELLING UNITS IN THE PACIFIC
NORTHWEST REGION

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March 1990

Prepared for
the Bonneville Power Administration
Contract No. DE-AI79-86BP64352

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BPA PERSPECTIVE

VENTILATION MEASUREMENTS IN ENERGY-EFFICIENT MULTIFAMILY DWELLING UNITS IN THE PACIFIC NORTHWEST REGION

Background

In 1983 the Northwest Power Planning Council (NWPPC) developed Model Conservation Standards in order to reduce energy use in electrically heated new residences. BPA's Residential Technology Section has conducted numerous studies and programs to test and evaluate the MCS. This project, which sought to measure air exchange rates in multifamily units built to the MCS, was completed under contract with Battelle's Pacific Northwest Laboratory.

Objectives

Originally, the study was intended to help increase the accuracy of the Standard Heat Loss Method (SHLM) of calculating heat loss and predict the air exchange rate for MCS multifamily units in the region. However, the sample was small, not random, and not statistically representative of MCS multifamily construction in the region. Therefore the objectives of the study were altered. The results should be viewed as case studies of ventilation characteristics.

Project Approach

Using the perflouorocarbon tracer (PFT) technique, researchers conducted eighty-eight air exchange rate measurements in four Washington state multifamily buildings built to Model Conservation Standards. With the cooperation of the building manager and tenants, two sample tubes were placed in each of 39 dwelling units; occupants returned the tubes by mail after two to four weeks.

Related ventilation data was also collected, including the following: ventilation air flow rate, amount of time the mechanical ventilation equipment was used, interior and exterior temperature during the measurements, wind speed, structural characteristics of the unit and building, and occupant characteristics and activities.

Key Findings

Key findings of the ventilation measurement study were as follows:

- The air exchange rate was highly variable between units, revealing the significant impact of occupant behavior on ventilation.
- The air exchange rate was less variable within each building than in the sample as a whole.
- A significant fraction of each unit's air flow comes from adjacent units. The greatest air flow was from lower units to upper units.
- Ventilation systems were out of balance, not maintained and not well understood by occupants.

More Information

This report is available from BPA's Residential Technology Section by calling (503) 230-5488 or writing to:

Bonneville Power Administration
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ABSTRACT

A ventilation field measurement study was conducted during the 1986/1987 and 1987/1988 heating seasons in 39 energy-efficient multifamily dwelling units. Four buildings, two in eastern Washington and two in western Washington, were involved in the study. The purpose of the study was to determine the total and baseline (natural) air exchange rates in units representing energy-efficient construction in the multifamily sector of the Pacific Northwest. This information will be used to aid in the development of future construction codes and standards.

The air exchange rate was measured using a multiple perfluorocarbon tracer (PFT) technique. Most measurements were taken over a 2- to 4-week period, with a few measurements taken over a period of one to three consecutive months. The PFT technique allows one to determine the fresh air flow into any unit within a building as well as the air flow between adjacent units. In addition, the volumetric air flow and usage of the mechanical ventilation system installed in the units were measured. Temperature, weather, structure, and occupanc / data were also collected.

EXECUTIVE SUMMARY

A ventilation field measurement study was conducted during the 1986/1987 and 1987/1988 heating seasons in 39 energy-efficient occupied multifamily dwelling units. The purpose of the study was to determine the total and baseline (natural) air exchange rates in multifamily units representing energy-efficient construction in the multifamily sector of the Pacific Northwest Region. The information is needed to increase the accuracy of the heat loss calculations of the Standard Heat Loss Method (SHLM) used by regional planners to evaluate the effectiveness of the Model Conservation Standards (MCS) and to assist in further development of future construction codes and standards in the Region. In addition, the study was envisioned to develop a model for predicting the air exchange rate for a typical heating season for MCS or equivalent code multifamily units in the region, based on the measured air exchange rates.

Four buildings were involved in the study, all in Washington state. Two buildings (a 2-story 12-plex and single story triplex) were located in eastern Washington and two buildings (both 2-story 12-plex) were located in Tacoma, Washington. All four buildings were mechanically ventilated. Two buildings had occupant-controlled air-to-air heat exchangers (AAHX), one building had a centrally-ducted AAHX, and one building had occupant-controlled exhaust fans.

A total of 88 short- and long- term air exchange rate measurements were taken using a multiple perfluorocarbon tracer (PFT) technique. Prior to this study, there was a dearth of data on ventilation in multifamily units, primarily because of the difficulty of using and interpreting data from other common measurement techniques used in multizone structures. These techniques include fan pressurization and single tracer gas decay.

The PFT technique using four distinct types of tracers was the best choice for cost-effective measurement of air exchange rates in multiple-zoned structures such as apartment buildings. The technique measures the inverse of the average PFT concentration over time (harmonic average). This is the pertinent quantity for air change rates for developing models and for

evaluating ventilation to control indoor pollutants. However, depending upon the variability of ventilation during the measurement period, it may not be as accurate for quantifying the arithmetic average air change (or infiltration) rate. This is the pertinent quantity for input into the SHLM calculation.

Additional data that are useful for understanding ventilation in this housing sector were also collected. These data include

- the mechanical ventilation air flow rate
- the usage of mechanical ventilation equipment (the amount of time the equipment is on)
- the interior temperature in each unit, outside temperature, and wind speed during the air exchange rate measurements
- structure characteristics for each unit and building
- occupant characteristics and a record of occupant activities in one 12-unit building during the air exchange rate measurements.

The PFT data quality and number of measurements in this study did not allow sufficient nor representative data to be taken for accurate model development. Furthermore, the sample was small and biased because we selected three buildings that were part of the Bonneville Power Administration (BPA) End-Use Load and Consumer Assessment metering program. The sample was therefore not statistically representative of MCS multifamily construction in the region. As a result, the regional mean air exchange rate in MCS (or equivalent code) multifamily construction could not be accurately quantified to increase the accuracy of the SHLM calculation.

These observations were discussed early in this study with BPA, and the objective and scope of the study were subsequently modified. The focus was shifted to acquiring ventilation measurements data in individual MCS multifamily units and whole buildings of various floor area and configuration and using the data as case studies of ventilation characteristics.

The data and analysis provide the following information on MCS multifamily ventilation in these four case-study buildings. The significance of the results is included:

- The total measured air exchange rate in the sample ranges from 0.010 to 1.25 air changes/hr (ACH) with a mean of 0.52 ± 0.34 ACH. The mean total ACH is near the code level of 0.5 ACH for the sample as a whole. However, the air exchange rate in seven of the units did not exceed 0.35 ACH during any of the measurement periods. The very large standard deviation (65% of the mean) indicates significant variability in air exchange rate across the sample. It is therefore difficult to quantify the mean air exchange rate in this sample with any certainty, and it is evident that present practices do not effectively control the air exchange rate in MCS multifamily structures.
- The mean air exchange rate for individual buildings shows a much lower standard deviation than the sample as a whole, ranging from 10% to 36% of the mean. This lower standard deviation indicates that ventilation rates were less variable in like-constructed and like-ventilated units than across the sample as a whole. This result seems logical given the diversity in occupants and ventilation strategy in each building.
- The measured air flow rate between units with common walls in the buildings averaged 15% of the total air flow rate into a unit (i.e., 85% was outside air). Air flow was found to be greatest from lower units to upper units. These data are the first quantitative indication in multifamily buildings that a small but significant fraction of the total air flow into a unit comes from an adjacent unit. Unfortunately, pollutants generated by neighbors comes with this air.
- The measured fresh air flow of the mechanical ventilation systems in the three of the buildings with AAHXs revealed that none of the systems was delivering the code-required 0.4 ACH air flow into the unit. Very little maintenance of the systems was evident, either by the occupant or by the building manager. The ventilation systems were also seriously out of balance. In addition, most occupants were unaware of the purpose or the operation of the ventilation system. The amount of time the ventilation systems were used was also recorded. In the three buildings with occupant-controlled systems, the mean usage of the ventilation equipment was 23% of the time during the ventilation testing. Similar findings have been noted in the MCS single family sector in the region.

In summary, because of the limited scope and size of this study, our understanding of ventilation the MCS multifamily sector in this region is still limited. The sample was small and defensible statistical correlations for model development were not possible. However, the study pointed out the significant influence occupants have on ventilation, particularly in the operation and maintenance of mechanical ventilation systems as evidenced by

the tremendous variability across the sample. This points out the need to further examine multifamily ventilation in both a controlled study where the occupancy and the ventilation systems are regulated and in a region-wide survey similar to that conducted in single family homes. The sample selection and design of such a study would be challenging because of the diverse nature of the multifamily sector.

ACKNOWLEDGMENTS

The author wishes thank those who assisted in conducting this project. Included are Richard Lee of Pacific Northwest Laboratory (PNL) who performed the PFT chemical analysis; Don Hadley of PNL who provided the weather and AAHX usage data from the End-Use Load and Consumer Assessment Program sponsored by Bonneville; Jim Bellamy, Scott Baker, and Bruce Carter of the Tacoma Public Utilities Conservation Office who assisted in the measurements in the Fife building; Mike Lubliner of the Washington State Energy Office who supplied structural data for the Pullman and Spokane buildings; Don Matson, Kevin and Jolene Kirkman, Al and Georgia Harbaugh, and Lee Chaffey, managers of the four buildings who assisted in the field work; Dominion Development and North Bay Development who volunteered the usage of the Fife and Tacoma buildings, respectively; and the tenants of the buildings who so willingly cooperated in the research effort. Finally, the author thanks Renee LaNore, Jeff Harris, and Phil Thor, the project managers at Bonneville, who supported this work, gave technical direction, and waited patiently for the final report.

CONTENTS

ABSTRACT	iii
EXECUTIVE SUMMARY	v
ACKNOWLEDGMENTS	ix
1.0 INTRODUCTION	1.1
2.0 APPROACH	2.1
2.1 SAMPLE DESIGN	2.1
2.2 SAMPLE SELECTION	2.1
2.3 RECRUITING	2.2
2.4 FIELD DATA COLLECTION	2.3
2.4.1 Structure and Occupancy	2.3
2.4.2 Equipment Usage	2.3
2.4.3 Environmental Data	2.4
2.4.4 Mechanical Ventilation	2.5
2.4.5 Air Exchange Rate	2.6
2.5 SCHEDULE	2.11
3.0 DESCRIPTION OF THE SAMPLE	3.1
3.1 PULLMAN BUILDING	3.1
3.2 SPOKANE BUILDING	3.2
3.3 FIFE BUILDING	3.3
3.4 TACOMA BUILDING	3.5
4.0 RESULTS	4.1
4.1 PULLMAN BUILDING	4.1
4.2 SPOKANE BUILDING	4.8
4.3 FIFE BUILDING	4.10

4.4	TACOMA BUILDING	4.17
5.0	DISCUSSION	5.1
5.1	GENERAL OBSERVATIONS	5.1
5.2	PULLMAN BUILDING	5.2
5.2.1	Mechanical Ventilation Measurements	5.2
5.2.2	PFT Measurements	5.3
5.2.3	Previous PFT Measurements	5.4
5.3	SPOKANE BUILDING	5.6
5.3.1	Mechanical Ventilation Measurements	5.6
5.3.2	PFT Measurements	5.7
5.3.3	Previous PFT Measurements	5.8
5.4	FIFE BUILDING	5.10
5.4.1	Mechanical Ventilation Measurements	5.10
5.4.2	PFT Measurements	5.11
5.5	TACOMA BUILDING	5.13
5.5.1	Mechanical Ventilation Measurements	5.13
5.5.2	PFT Measurements	5.14
6.0	CONCLUSIONS	6.1
6.1	LESSONS LEARNED	6.1
6.1.1	Sample Selection	6.1
6.1.2	Recruiting	6.2
6.1.3	Field Measurements	6.2
6.2	COSTS	6.4
7.0	REFERENCES	7.1
	APPENDIX A - FORMS	A.1
	APPENDIX B - OCCUPANT ACTIVITY RECORDS FOR THE TACOMA BUILDING	B.1

FIGURES

2.1	Pullman Building PFT Configuration	2.7
2.2	Spokane Building PFT Configuration	2.8
2.3	Fife Building PFT Configuration	2.9
2.4	Tacoma Building PFT Configuration	2.10
4.1	Air Exchange Rates and Unit-to-Unit Air Flows for the Pullman Building, Test Period 1.	4.4
4.2	Air Exchange Rates and Unit-to-Unit Air Flows for the Pullman Building, Test Period 2	4.5
4.3	Air Exchange Rates and Unit-to-Unit Air Flows for the Pullman Building, Test Period 3	4.6
4.4	Air Exchange Rates and Unit-to-Unit Air Flows for the Spokane Building, Test Period 1	4.12
4.5	Air Exchange Rates and Unit-to-Unit Air Flows for the Spokane Building, Test Period 2	4.13
4.6	Air Exchange Rates and Unit-to-Unit Air Flows for the Spokane Building, Test Period 3	4.14
4.7	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 1	4.21
4.8	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 2	4.22
4.9	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 3	4.23
4.10	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 4	4.24
4.11	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 5	4.25
4.12	Air Exchange Rates and Unit-to-Unit Air Flows for the Fife Building, Test Period 6	4.26
4.13	Air Exchange Rates and Unit-to-Unit Air Flows for the Tacoma Building	4.28

5.1	Air Exchange Rates and Unit-to-Unit Air Flows for the Pullman Building RSDP Evaluation	5.5
5.2	Air Exchange Rates and Unit-to-Unit Air Flows for the Spokane Building RSDP Evaluation	5.9

TABLES

2.1	Schedule of Tests	2.12
3.1	Description of the Sample Buildings	3.2
3.2	Key Characteristics of the Sample Buildings and Units	3.2
3.3	Characteristics of the Units in the Pullman Building	3.3
3.4	Characteristics of the Units in the Spokane Building	3.3
3.5	Characteristics of the Units in the Fife Building	3.4
3.6	Characteristics of the Units in the Tacoma Building	3.5
4.1	AAHX Air Flow Measurements in the Pullman Building	4.2
4.2	Summarized Measurement Data for the Pullman Building	4.7
4.3	AAHX Air Flow Measurements in the Spokane Building	4.9
4.4	Summarized Measurement Data for the Spokane Building	4.11
4.5	AAHX Air Flow Measurements in the Fife Building	4.15
4.6	Summarized Measurement Data for the Fife Building	4.18
4.7	Summarized Air Exchange Rate and Occupant Activity Data for the Tacoma Building	4.27

1.0 INTRODUCTION

Air infiltration accounts for 20% to 30% of the energy used for space heating in dwelling units. Extensive studies in this country, and particularly in the Pacific Northwest region, have measured and documented the range of air exchange rates in single-family homes (DOE 1988, PNL 1988, Parker et al. 1989a). However, only recently has there been documentation of the measured air exchange rates in multifamily dwelling units, particularly in newer buildings and those constructed to energy-efficient construction standards (Kolb and Baylon 1988). It has been suggested that the baseline fresh air exchange rates in multifamily units are lower than those for single-family residences and perhaps lower than those calculated or estimated using current models (DOE 1988).

The Model Conservation Standards (MCS), which were developed by the Northwest Power Planning Council (NWPPC) and supported by the Bonneville Power Administration (BPA), mandate certain air exchange rates for multifamily dwelling units (NWPPC 1986). Several jurisdictions in the BPA service territory have adopted or are considering adoption of all or portions of the MCS. Consequently, hundreds of multifamily units have been or are being constructed in the region to the MCS or equivalent standards and codes.

Heating season air exchange rate data are needed on these units, primarily to increase the accuracy of the heat loss calculations of the Standard Heat Loss Method (SHLM) used by the regional planners to evaluate the effectiveness of the MCS. Specifically, there is a need to increase the accuracy of heat loss calculations by decreasing the uncertainty in the baseline infiltration component of the model. Data are also needed to evaluate the ability of the regional builders to meet the air exchange rate specifications in the MCS or equivalent codes, especially in the specification of mechanical ventilation systems.

Therefore, a broad-based ventilation measurement study was undertaken in the region in new energy-efficient multifamily units to quantify and better

understand ventilation. This study was sponsored by the Residential Technology Section of the BPA and conducted by the Pacific Northwest Laboratory.^(a)

Air exchange rate, mechanical ventilation, structure, and occupant data were acquired in 39 multifamily units (apartments) in this study. Twenty-four units were located in the Tacoma Public Utilities service territory of western Washington. Twelve of these units were constructed to the 1984 Tacoma Energy Code, and 12 were constructed to the 1986 Tacoma Energy Code (Tacoma Public Utilities 1984, 1986). Fifteen units were located in eastern Washington and were constructed in 1984 to the MCS under the Residential Standards Demonstration Program (RSDP) (Parker and Foley 1986, Parker et al. 1989b). Every unit in this study was equipped with a mechanical ventilation system. Twenty-seven of these units were tested during the 1986 heating season, and twelve units were tested during the 1987 heating season.

The purposes of the study, identified during the iterative scoping phase of the study were: 1) to measure the air exchange rates between adjacent units and between the units and the exterior of the building and 2) to develop a model for predicting the fresh air exchange rate in an average heating season for MCS or equivalent code multifamily units in the region, based on these measured air exchange rates.

Because of the limitations in the budget and, therefore, the sample size, duration, and number of measurements taken in individual units, only the first purpose was achieved in this study. The quality and amount of data were not adequate for developing a heating season model to predict air exchange rates. However, the data are useful as case studies of ventilation in energy-efficient multifamily units and buildings. Therefore, this report presents the results of each multifamily building tested as an individual case study. It presents and discusses the following topics:

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

- the unit and building air exchange rates
- the mechanical ventilation component of the measured total air exchange rate
- the usage of mechanical ventilation equipment
- the measurements of the interior temperature in each unit, outside temperature, and wind speed at each building during the air exchange rate measurements
- structure characteristics for each unit and building
- occupant characteristics and occupant activities in the building in Tacoma during the air exchange rate measurements.

2.0 APPROACH

The following discussion describes the approach used to conduct the field experiments in the multifamily buildings.

2.1 SAMPLE DESIGN

The scope of the project did not allow the selection and testing of a statistically representative sample of MCS multifamily dwellings in the region. Instead, a decision was made at the beginning of the project to test approximately 40 units in at least two distinct climate zones in the region. In addition, it was desired that the units tested cover a range of typical apartment units in the region meeting the following structural criteria:

- total heated square footage in the units ranging from 600 to 800 ft², 800 to 1000 ft², and >1000 ft²
- units with adjacent apartment units on one, two, and three sides, counting the floor and ceiling as sides (this criterion required that one- and two-story buildings be tested).

No other criteria were required in the sample except the willingness of the building owners, managers, and occupants to participate in the study.

2.2 SAMPLE SELECTION

During the time of this study, PNL was also monitoring electrical usage in several MCS multifamily buildings in all three climate zones in the region under the End-Use Load and Consumer Assessment Program (ELCAP) being conducted for BPA. Forty-five units in five MCS buildings were being monitored (Parker et al. 1989b). One building was in Idaho Falls, Idaho; one building, in Pullman, Washington; one building, in Spokane, Washington; one building, in Seattle, Washington; and one building, in Fife, Washington. The Seattle building was an owner-occupied condominium; the remaining buildings were rental apartments. Of these candidate buildings, the Pullman, Spokane, and Fife buildings were chosen for testing.

In each of the ELCAP study apartments, the indoor temperature and the end uses of electricity were monitored onsite using real-time data-logging

equipment. In addition, wind speed, wind direction, insolation, and outdoor temperature were monitored at selected apartment buildings with an ELCAP weather station.

PNL had already acquired information on the occupants of the ELCAP-monitored buildings, knew the managers, and had worked with the owner and/or manager of each building monitored during the installation of ELCAP equipment. These were important criteria for selecting buildings to test in this study because of the limited resources for recruiting occupants. The ELCAP buildings and apartments also fit all of the structural criteria identified in the sample design. Our familiarity with the occupants, owners, and managers and the availability of the ELCAP monitoring data made these buildings primary candidates for this study.

The Tacoma Public Utilities Conservation Office cooperated to identify non-ELCAP monitored buildings that met the structural criteria for this study. Tacoma had adopted the principal components of the MCS in its building code in February 1984 and was interested in acquiring air exchange rate data for multifamily buildings in their service territory. An apartment complex under construction in Fife, Washington, was identified as a possible candidate for testing. Tacoma Public Utilities secured the cooperation of the builder to work with PNL in the study. PNL, in agreement with BPA, decided that a single building in this complex could be included in both the ELCAP multifamily study and this study. A 12-unit building was therefore prewired by PNL, ELCAP metering equipment was installed before the apartments were occupied, and the building was included in this study. In addition, the Tacoma Public Utilities Conservation Office identified a 12-unit building under construction in South Tacoma as a candidate for ventilation testing.

2.3 RECRUITING

The occupants of the units to be tested were recruited with the assistance of the owners and managers of each apartment complex. The occupants were required to sign an Access Agreement before PNL conducted the experiments (see Appendix A). The managers of the Pullman, Fife, and Tacoma buildings distributed the agreements and accompanying letters of explanation and

collected the signed agreements from each occupant. The managers of the Spokane buildings first contacted the occupants and PNL subsequently mailed them agreements. The occupants signed the agreements and mailed them directly to PNL.

The managers of all the buildings informed PNL of any occupant turnover or vacancy during the period of the testing. Extra letters and agreements were left with each manager for new occupants to sign and mail directly to PNL.

2.4 FIELD DATA COLLECTION

The methods and equipment used to collect the ventilation and supporting data are described in the following sections.

2.4.1 Structure and Occupancy

The Washington State Energy Office (WSEO) provided the construction specifications for the Pullman and Spokane buildings from the RSDP Design Review Compliance and Point System documents and provided the floor plans of the buildings from blueprints. Tacoma Public Utilities supplied Energy Standards Permit Applications and architectural drawings of the Fife and Tacoma buildings. PNL acquired other information, such as the manufacturer of the ventilation equipment, during the testing.

The building managers supplied the number of occupants in each unit. The actual number of occupants during the testing was sometimes difficult to determine, even by the management, particularly in the Pullman building. A "best estimate" was used in some apartments of this building.

2.4.2 Equipment Usage

The number of hours of usage of the mechanical ventilation equipment in the Spokane building and in 9 of the 12 units in the Fife building was acquired from ELCAP metered data. The circuit breakers for the ventilation equipment (a ducted air-to-air heat exchanger [AAHX]) in the individual units of these buildings were metered in the ELCAP. Occupants of these buildings were not asked to record usage of mechanical ventilation equipment because the metered data were considered to be more accurate records of usage. In

retrospect, the occupants of the three units in Fife that were not ELCAP-metered should have been requested to keep daily records of ventilation equipment usage.

The fresh air flow of the AAHX at each speed setting was measured (see Section 2.4.4). The power consumption associated with each speed setting and the number of hours of operation at the known power consumption were acquired from the ELCAP data. The volume of fresh air into a unit during a testing period was calculated from these data. Other equipment usage, such as the fireplace, dryer, or bath fan usage, was not monitored or recorded in either of these buildings.

The Pullman building is served by a central AAHX. The ELCAP metering provided data on the operation of this central unit. During the test periods, the AAHX was continuously operated at a single speed, supplying fresh air to each unit of the Pullman building.

The occupants of the Tacoma building kept daily activity records (see Appendix B) to record estimated usage (hours or minutes) of the ventilation system, fireplace, and dryer, as well as window openings and special activities in the apartment. These data are only qualitative.

2.4.3 Environmental Data

Indoor temperatures were recorded in the ELCAP-monitored units from a shielded thermistor (sensor) mounted in an enclosure on an interior wall of each unit. The accuracy of the thermistor is $\pm 1^{\circ}\text{C}$. Temperature data were acquired from a single living area sensor in each of the Pullman and Spokane building units. The indoor air temperature data in nine of the Fife units were acquired from the average of two temperature sensors, one located in the master bedroom and one located in the main living area. In the remaining three units of the Fife building, temperatures were recorded from ELCAP monitoring at a single sensor in the living area.

The indoor temperatures in the 12 units of the Tacoma building were recorded using an ACR 101(a) temperature recorder placed in the hallway of

(a) ACR 101 is a product of A.C.R. Systems, Inc., Surrey, British Columbia, Canada.

each unit. The ACR 101 records time-series temperature data at 1-second intervals, averages the readings, and records a 20-minute average. The accuracy of the recorder is $\pm 1^\circ\text{F}$. The recorders were set out, activated, and then recovered at the end of the test period. The recorders were interrogated and analyzed, and the data were stored by PNL. Indoor temperatures were also recorded once in the main living area of each unit using a bimetallic thermometer at the start of the test period.

Outdoor temperatures, wind speeds, and wind directions were recorded from ELCAP weather stations located on the Spokane and Fife buildings. Although there was an ELCAP weather station on the Pullman building, the equipment failed to operate, so representative outdoor temperature data were gathered from a nearby weather station in Pullman. No wind speed data were available for the Pullman building.

Representative wind speed data for the Tacoma building were acquired from a nearby ELCAP weather station located on a single-family residence in South Tacoma. Outside temperature data were acquired from an ACR 101 temperature recorder set under the eaves on the north side of the building during the test period.

2.4.4 Mechanical Ventilation

The AAHX flow rates were measured in the Pullman, Spokane, and Fife buildings units with a Davis Instrument Manufacturing Co. wind vane anemometer. The anemometer measures the cumulative air flow in linear feet passing through the anemometer for a given recorded time period. The readings were divided by the elapsed time, and the volumetric flow was determined from a calibrated conversion factor. The accuracy of the anemometer is $\pm 1\%$ of the reading; the resolution is ± 1 ft/minute.

The anemometer was mounted in a holder shaped to allow it to be sealed against rectangular or circular ducts and grills. The custom-designed mount ensured that all of the air would flow through the meter with minimal pressure drop. However, no measure of pressure drop was recorded nor was pressure correction made in the flow data. Therefore, the accuracy of the flow measurement is estimated to be $\pm 6\%$.

2.4.5 Air Exchange Rate

The air exchange rate was measured in each unit of the four buildings and in the building as a whole using the perfluorocarbon tracer (PFT) technique (Dietz et al. 1985). Up to four different PFT types were deployed in the measurements: perfluoromethylcyclohexane (PMCH), perfluoromethylcyclopentane (PMCP), perfluorodimethylcyclohexane (PDCH), and perfluorodimethylcyclobutane (PDCB). Different types of tracers were deployed in the units so that the air flow between units could be ascertained along with the fresh air exchange rate in each unit.

The protocol used for the measurements generally followed the protocol recommended by Brookhaven National Laboratory (BNL), although it was modified to accommodate the total number of sources available (Dietz 1986). Because most of the units were small, sources were placed in only one location in the units in the Pullman, Spokane, and Fife buildings; they were placed in two locations in some of the larger (three-bedroom) units in the Tacoma building.

Some PFT sources were supplied by BNL, but most were manufactured by PNL. Those manufactured by PNL were less reliable than those from BNL. Difficulties with the PFT sources are discussed in more detail in Sections 4 and 5. The PFT sample tubes were hung 16 in. from the ceiling in foam holders, normally in pairs. In a few units, additional sample tubes were hung in a different location in the unit to ascertain the spatial (zonal) variation in air exchange rate. The source and sample tube deployment strategies for each building are identified in Section 4.

The sources and sample tubes were placed and recovered by PNL in all buildings except the Fife building. In the Fife building, PNL placed the sources and sample tubes for the first experiment; personnel from the Tacoma Public Utilities Conservation Office recovered and set out the sample tubes for all remaining tests. Figures 2.1 to 2.4 illustrate the PFT configurations for each building, indicating the type of PFT source.

The PFT captured in the sample tubes was chemically analyzed at PNL. The analysis results were combined with structure volume, temperature, and

Pullman Building

Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
PMCP	PDCB	PMCP	PDCB	PMCP	PDCH
Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12
PMCH	PDCH	PMCH	PDCH	PMCH	PDCB
Storage Rooms					

R9001130.6

FIGURE 2.1. Pullman Building PFT Configuration

Spokane Building

R9001130.1

FIGURE 2.2. Spokane Building PFT Configuration

Fife Building

R9001130.19

FIGURE 2.3. Fife Building PFT Configuration

Tacoma Building

R9001130.11

FIGURE 2.4. Tacoma Building PFT Configuration

PFT source rate data in a matrix solution program to produce the unit air exchange rate and the air flow between adjacent units.

The key values for the measurements and the analysis of ventilation are the baseline (or natural) fresh air exchange rate, the total (baseline + mechanical) fresh air exchange rate, and the flow of air between units. Studies suggest that the total air exchange rate in a mechanically ventilated structure is somewhat less than the sum of the baseline plus the mechanical air exchange rate (Shaw 1985). However, in this study the baseline air exchange rate was determined by subtracting the air exchange rate supplied by the mechanical ventilation device (derived from the AAHX volume flow, apartment volume, and metered usage of the AAHX over the time period of the test) from the total air exchange rate measured with the PFT test. This assumption will create an error of less than 5% in the determination of baseline air exchange rate.

Approximately 20% of the units had long-term (longer than 4 weeks) air exchange rate tests. These data are useful for assessing the representativeness of the short-term (2- to 4-week) tests in determining baseline seasonal air exchange rates. Quantifying the usage of the mechanical ventilation equipment in the units is critical for long-term measurement analysis because wide variations in the air exchange rate due to the operation of the mechanical system will result in a significant bias in the PFT results (Kolb and Baylon 1988).

2.5. SCHEDULE

Table 2.1 gives the schedule of the tests in each building. At least one air exchange rate measurement of between 2- and 4-weeks duration was taken in each unit of each building. In some of the units of the buildings, a single long-term air exchange rate test was also taken during the time of several consecutive short-term tests.

TABLE 2.1. Schedule of Tests

<u>Building</u>	<u>Unit</u>	<u>Test Dates (mo/d/yr)</u>	
		<u>PFT^(a) Testing</u>	<u>Air Flow Measurements</u>
Pullman	1	01/14/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
		03/05/87 to 03/30/87	
		01/14/87 to 03/30/87	
	2,8	01/14/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
		03/05/87 to 03/30/87	
	3,4,10	01/14/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
	5,6,9,11	01/13/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
	7	01/13/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
		03/05/87 to 03/30/87	
	12	01/15/87 to 02/06/87	02/06/87
		02/06/87 to 03/05/87	
Spokane	1730	02/11/87 to 03/05/87	02/11/87
		03/05/87 to 03/30/87	
		02/11/87 to 03/30/87	
	1732	02/11/87 to 03/05/87	02/11/87
		03/05/87 to 03/30/87	
	1734	02/11/87 to 03/06/87 03/06/87 to 03/30/87	02/11/87
Fife	6617/#1	11/13/86 to 12/16/87	02/05/87
	6617/#2	01/14/87 to 02/05/87	
	6617/#3	02/05/87 to 03/03/87	
	6617/#4	11/13/86 to 03/03/87 03/03/87 to 03/ /87	
	6619/#1	11/13/86 to 12/16/87	02/05/87
	6621/#3	01/14/87 to 02/05/87	
		11/13/86 to 02/05/86	

TABLE 2.1. (contd)

Building	Unit	Test Dates (mo/d/yr)	
		PFT ^(a) Testing	Air Flow Measurements
Fife	6619/#2	11/13/86 to 12/16/87	
	6619/#3	01/14/87 to 02/05/87	02/05/87
	6619/#4		
	6621/#1		
	6621/#2		
	6621/#4		
Tacoma	8701/A	01/15/88 to 01/30/88	NM ^(b)
	8701/B		
	8701/D		
	8703/A		
	8703/B		
	8703/D		
	8705/A		
	8705/D		
	8701/C	01/16/88 to 01/30/88	NM
	8703/C		
	8705/B		
	8705/C		

(a) PFT - perfluorocarbon tracer.

(b) NM - not measured.

3.0 DESCRIPTION OF THE SAMPLE

The four buildings monitored in this study were constructed to the MCS or Tacoma Energy Code. They were located in Pullman, Spokane, Fife, and Tacoma in the state of Washington.

The Pullman building is located near the Washington State University Campus in an industrial area. The Spokane building is located in an older well-developed residential area near the center of Spokane. The Fife building is part of a large multifamily complex near the I-5 freeway in Fife. The Tacoma building is also part of a large complex in a mixed residential and commercial neighborhood south of Tacoma. The Pullman and Spokane buildings are in climate zone 2, and the Fife and Tacoma buildings are in climate zone 1^(a). Table 3.1 is a general description of the four buildings.

The structural characteristics of the buildings and the units tested in each building are important for evaluating the representativeness of the sample for the region. These characteristics are given in Table 3.2.

3.1 PULLMAN BUILDING

The Pullman building consists of 12 two-bedroom units of identical size (see Figure 2.1). There are two levels of apartments above ground-level storage rooms and a laundry room. There are no stairwells inside the building, and all units are accessible from a front walkway that spans each level. The building was constructed to the MCS as part of the RSDP. It was constructed with infiltration package "C," meaning that the target baseline air exchange rate is 0.1 ACH and the target total air exchange rate is 0.5 ACH.

(a) The NWPPC and the BPA have established three Northwest climate zones, 1, 2, and 3. Zone 1 is a mild climate with 4,000 to 6,000 heating degree days (primarily west of the Cascade range); zone 2 is a less temperate climate with 6,000 to 8,000 heating degrees (the eastern part of the region); and zone 3 has over 8,000 heating degree days (western Montana and higher elevations).

TABLE 3.1. Description of the Sample Buildings

<u>Building</u>	<u>Year Built</u>	<u>No. Units</u>	<u>No. Units Tested</u>	<u>Stories</u>	<u>Insulation R Values (b)</u>			<u>Windows</u>	<u>Shield Class</u>	<u>Terrain</u>
					<u>Ceiling</u>	<u>Wall</u>	<u>Floor</u>			
Pullman	1984	12	12	3 ^(a)	30	19	30	(c)	IV	IV
Spokane	1985	3	3	1	38	19	15	(d)	III	III
Fife	1986	12	12	2	30	19	10	(e)	III	II
Tacoma	1987	12	12	2	38	19	10	(f)	III	III

(a) Storage units on ground floor; apartments above storage units (see Figure 2.1).

(b) Vapor barrier installed with the insulation in all buildings.

(c) Aluminum-framed slider; double glazing with storm window.

(d) Energy-efficient slider; double glazing with storm window.

(e) Aluminum-framed slider; double glazing.

(f) Energy-efficient slider; double glazing.

TABLE 3.2. Key Characteristics of the Sample Buildings and Units

<u>Building</u>	<u>No. of Units with ft² of:</u>			<u>No. of Units with Adjacent Units on:</u>		
	<u>600 to 800</u>	<u>800 to 1000</u>	<u>>1000</u>	<u>1 Side^(a)</u>	<u>2 Sides^(a)</u>	<u>3 Sides^(a)</u>
Pullman	12	0	0	0	4	8
Spokane	3	0	0	2	1	0
Fife	0	12	0	0	4	8
Tacoma	0	6	6	0	4	8

(a) Including floors and ceilings as sides.

The building is equipped with a central AAHX for the entire building (Heat-X-Changer Model HX-800).^(a) In each unit, there are fresh air ducts in the bedrooms, a stale air return duct in the living/kitchen area, and a bathroom fan (of unknown type). There is no AAHX control in the units, and they are zone-heated with baseboard heat. The units were occupied primarily by college students during the testing. Table 3.3 summarizes the location and size of the units and the number of occupants in the Pullman building.

(a) Heat-X-Changer Model HX-800 is a product of Heat-X-Changer Corporation, Minneapolis, Minnesota.

3.2 SPOKANE BUILDING

The Spokane building is a single-level triplex of identical two-bedroom units (see Figure 2.2). There is a periodically heated 160-ft² laundry room adjacent to the north end unit. The building was constructed to the MCS as part of the RSDP. It was constructed with infiltration package "C," and each unit is equipped with a ducted AAHX (Heat-X-Changer) controlled with an on/off (high speed only) switch. The AAHX has fresh air ducts in the bedrooms and stale air return ducts in the bathroom and in the kitchen. The units are heated with zoned baseboard heat. Table 3.4 gives characteristics of the building.

TABLE 3.3. Characteristics of the Units in the Pullman Building

Unit	Level	Floor Area (ft ²)	Volume (ft ³)	Bedrooms	No. of Occupants
1	3	736	5704	2	2
2	3	736	5704	2	2
3	3	736	5704	2	2
4	3	736	5704	2	2
5	3	736	5704	2	2
6	3	736	5704	2	1
7	2	736	5704	2	3
8	2	736	5704	2	3
9	2	736	5704	2	2
10	2	736	5704	2	2
11	2	736	5704	2	2
12	2	736	5704	2	1

TABLE 3.4. Characteristics of the Units in the Spokane Building

Unit	Level	Floor Area (ft ²)	Volume (ft ³)	Bedrooms	No. of Occupants
1730	1	780	6045	2	2
1732	1	780	6045	2	3
1734	1	780	6045	2	1

3.3 FIFE BUILDING

The Fife building has 12 two-bedroom units; six units are upstairs, and six units are downstairs (see Figure 2.3). There is a pair of units (one up and one down) on each end of the building with a stairwell separating an adjacent quad of units (two up and two down). There is also a stairwell separating the two middle quads. Each unit has a "zero clearance" fireplace with an outside air intake, a sliding glass door to a patio, and a dryer vented to the outside. The upstairs units have vaulted ceilings in the living area. The building was constructed to the 1984 Tacoma Energy Code which requires a baseline air exchange rate of 0.1 ACH and a total air exchange rate of 0.5 ACH. There is a ducted AAHX (Nutone AE-200)^(a) in each unit with fresh air ducts in the bedrooms and the living area and stale air return ducts in the bathroom and kitchen. The AAHXs are controlled with dehumidistats.

This building is part of the ELCAP multifamily sample and therefore is monitored for indoor temperature and end use of electricity. Nine of the units have ELCAP or end-use metering equipment and two indoor temperature sensors, one in the master bedroom and one in the living area. The remaining three units have only a single temperature sensor in the living area and no end-use metering equipment. There is an ELCAP weather station installed on the building. Table 3.5 gives the characteristics of the building units.

3.4 TACOMA BUILDING

The Tacoma building is similar to the Fife building with a pair of units on each end and two quads in the middle of the building. Stairwell location is the same (see Figure 2.4). There are six three-bedroom units and six two-bedroom units. The upper units have vaulted ceilings in the living room. Each unit is equipped with an "zero clearance" fireplace with an outside air intake, a sliding glass door to a small patio, and a dryer exhausted to the outside.

(a) The Nutone AE-200 is a product of Nutone Housing Group, Division of Scovill, Cincinnati, Ohio.

TABLE 3.5. Characteristics of the Units in the Fife Building

<u>Unit</u>	<u>Level</u>	<u>Floor Area (ft²)</u>	<u>Volume (ft³)</u>	<u>Bedrooms</u>	<u>No. of Occupants</u>
6617/1	1	847	6564	2	3
6617/2	1	847	6564	2	4
6617/3	2	847	6820	2	2
6617/4	2	847	6820	2	2
6619/1	1	847	6564	2	2
6619/2	1	847	6564	2	2
6619/3	2	847	6820	2	3
6619/4	2	847	6820	2	4
6621/1	1	847	6564	2	1
6621/2	1	847	6564	2	2
6621/3	2	847	6820	2	2
6621/4	2	847	6820	2	4

The building is constructed to the 1986 Tacoma Energy Code (Tacoma Public Utilities 1986). The target total air exchange rate for each unit is 0.35 ACH. Mechanical ventilation is supplied by one exhaust fan in the bathroom and one in the laundry closet. The fans are Nutone QT 80s (80 cfm, 1.5 sones), ducted to the outside with a 10- to 30-foot run of 4-in. diameter flexible insulated ducting. Each unit is also equipped with a kitchen range hood exhausted to the outside. The bath exhaust fan is controlled with a dehumidistat and booster timer switch. The laundry closet fan is controlled with a timer. Table 3.6 gives the characteristics of the units.

TABLE 3.6. Characteristics of the Units in the Tacoma Building

<u>Unit</u>	<u>Level</u>	<u>Floor Area (ft²)</u>	<u>Volume (ft³)</u>	<u>Bedrooms</u>	<u>No. of Occupants</u>
8701/A	1	1111	8888	3	3
8701/B	1	1111	8888	3	3
8701/C	2	1111	9250	3	4
8701/D	2	1111	9250	3	3
8703/A	1	961	7688	2	3
8703/B	1	961	7688	2	3
8703/C	2	961	8050	2	2
8703/D	2	961	8050	2	3
8705/A	1	961	7688	2	1
8705/B	1	1111	8888	3	5
8705/C	2	961	8888	2	4
8705/D	2	1111	8050	3	2

4.0 RESULTS

Each of the buildings is treated as a case study, so the results will be presented by building. Much of the information is presented in tabular form, and a discussion of the results is found in Section 5.

The benefit of the multiple PFT technique is the ability to determine fresh air flows both into units and between units. The PFT data are therefore analyzed in a multiple zone matrix program developed by BNL which allows the infiltration rates, air flows, and standard errors to be determined for up to four distinct zones simultaneously. Therefore, air flows (in m^3/hr) into and out of each unit of the building tested are quantified and shown in the figures in this section.

There were considerable unusable PFT data from the Pullman and Fife buildings, primarily because of the PNL-made PFT sources placed in some units. The chemical analyses of some samples were also unusable. Some sources did not release PFT as anticipated, so the source rates were too low and/or suspect for these sources and could not be quantified for analysis. In addition, the PDCB PFT used as the tracer in a number of the units interfered with the analysis of PMCP that was used as the tracer in adjacent units. The PDCB and PMCP peaks elute on the gas chromatograph at approximately the same time making the peaks indistinguishable from one another. Therefore, it was not possible to quantify both the PDCB and PMCP tracers in some sample tubes, and the data were lost.

4.1 PULLMAN BUILDING

The Pullman building was tested from January 13 through March 30, 1987. All of the units were tested for a minimum of two consecutive test periods of 22 to 24 days and 27 days. Four adjacent units (Units 1, 2, 7, and 8) were tested for an additional 25 days, and one unit (Unit 1) had sample tubes exposed for the entire testing period of 75 consecutive days (see Table 2.1). Sources were left in Units 1, 2, 7, and 8 for the entire 75 days of testing.

The fresh air flow in each unit from the central AHX was measured at the start of the second test period. The fresh air flow data are given in

Table 4.1. Measurements were taken with the doors and windows closed. It was assumed that the air flows did not vary significantly during the time period of the testing, so the one-time flow measurement data were used for all ventilation calculations. Because of the length of the PFT testing and the lack of regular maintenance on the central system, the estimated error in the ventilation flow data is $\pm 5\%$. This error is not reflected in the data in Table 4.1.

The central AAHX was operated continuously during the entire period of testing. Therefore, the total fresh air flow in each unit (except Unit 11) from the AAHX operation was calculated by multiplying the number of hours for each PFT test period by the total fresh air flow rate given in Table 4.1.

Four PFT source types were deployed in the units of the building: PMCP, PDCB, PMCH and PDCH (see Figure 2.1). All sources were manufactured by PNL and were weighed before deployment and at the end of the testing to estimate

TABLE 4.1. AAHX Air Flow Measurements in the Pullman Building

Unit	Fresh Air Flow (cfm)			Fresh Air Temperature (°F)	Stale Air Return Flow (cfm)
	Vent #1	Vent #2	Total		
1	11.5	12.5	24.0	55	6.1
2	15.2	15.7	30.9	54	NM(a)
3	12.5	12.5	25.0	56	0
4	11.8	11.7	23.5	56	4.0
5	10.8	11.3	22.1	57	4.9
6	11.1	10.6	21.7	56	0
7	14.4	14.1	28.5	53	7.6
8	14.5	14.4	28.9	54	6.5
9	13.8	13.2	27.0	54	6.4
10	12.8	13.1	25.9	52	5.0
11	(b)	(b)	(b)	NM	0

(a) NM - not measured.

(b) Grill was sealed and taped, no air flow.

the PFT emission rates. The sources were placed at the same time that the sample tubes were set in each unit for the first test period.

With the exception of Units 2, 3, and 12, the sources were placed inside the ELCAP temperature sensor enclosure. The sources in Units 2, 3, and 12 were placed on top of the kitchen cabinet, near an inside wall. The source temperature in each unit was determined from ELCAP temperature monitoring data. Although the sources were not located according to ideal protocol, the small volume of the units and the presence of an AAHX ensured good mixing of the PFT.

To begin the data analysis, the building was divided into three quads for four zone PFT analysis: Units 1, 2, 7, and 8; Units 3, 4, 9, and 10; and Units 5, 6, 11, and 12. The air exchange rates and unit-to-unit air flows (m^3/h) for each test period are shown in Figures 4.1 to 4.3. Those units with unusable or no PFT data were necessarily excluded from the four zone analysis, and no air exchange rate or air flow data are shown for these units. When the data in a unit were unusable, the building zones were reconfigured to include adjacent units with usable data, and the analysis program was rerun.

Table 4.2 summarizes the air exchange rate measurements, mechanical ventilation, and environmental data collected from the Pullman building tests. The baseline air exchange rate of each unit was calculated assuming that the air exchange rate provided by mechanical ventilation is directly additive to the baseline air exchange rate to obtain the total air exchange rate of the unit. This is the most straightforward approach to estimating natural ventilation in structures with mechanical ventilation. Additional research is needed to determine if a variation to this approach (such as subtracting, in quadrature, the mechanical ventilation component) is more accurate, but this determination is beyond the scope of this study.

The schedule of measurements (see Table 2.1) shows that the sample tubes were exposed during some test periods that vary by ± 2 days among the units during the test period (i.e., tubes were set out in the units over a 2-day

Pullman Building

FIGURE 4.1. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Pullman Building, Test Period 1 (air flows are shown in bold type)

R9001130.9

Pullman Building

R9001130.10

FIGURE 4.2. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Pullman Building, Test Period 2 (air flows are shown in bold type)

Pullman Building

R9001130.7

FIGURE 4.3. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m^3/hr) for the Pullman Building, Test Period 3 (air flows are shown in bold type)

TABLE 4.2. Summarized Measurement Data for the Pullman Building

Test Period 1 (01/13/87 to 02/06/87--24 days)

Average Outdoor Temperature: 27.4°F

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX ACH ^(c)	Baseline ACH
			Infiltration (m ³ /h)(SD) (a)	ACH ^(b) (SD)		
1	71.1	2	BD ^(d)	BD	0.25	-
2	69.8	4(c)	78(8.5)	0.49(0.05)	0.325	0.165
3	73.4	2	BD	BD	0.26	-
4	72.5	2	BD	BD	0.25	-
5	70.5	2	BD	BD	0.23	-
6	73.9	2	141(21)	0.87(0.14)	0.23	0.64
7	69.6	2	BD	BD	0.30	-
8	66.3	2	BD	BD	0.30	-
9	72.9	2	50(11)	0.31(0.07)	0.28	0.03
10	70.3	2	156(97)	0.97(0.60)	0.27	0.70
11	68.2	2	24(7)	0.15(0.04)	0.0	0.15
12	74.5	2	85(15)	0.53(0.09)	0.275	0.255

Test Period 2 (02/06/87 to 03/05/87--27 days)

Average Outdoor Temperature: 38.7°F

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX ACH	Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)		
1	70.5	2	BD	BD	0.25	-
2	68.7	2	133(13)	0.82(0.09)	0.325	0.495
3	72.9	2	BD	BD	0.26	-
4	73.6	2	BD	BD	0.25	-
5	NA ^(e)	2	BD	BD	0.23	-
6	74.3	2	202(23)	1.25(0.155)	0.23	1.02
7	69.4	2	BD	BD	0.30	-
8	66.0	2	BD	BD	0.30	-
9	72.1	2	37(5)	0.23(0.03)	0.28	~0
10	69.4	2	BD	BD	0.27	-
11	68.4	2	BD	BD	0.0	-
12	74.1	2	98(10)	0.61(0.06)	0.275	0.335

TABLE 4.2. (contd)

Test Period 3 (03/05/87 to 03/30/87--25 days)
Average Outdoor Temperature: 43.8°F

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX ACH	Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)		
1	71.0(f)	2(f)	BD	BD	0.25	-
2	68.5	2	BD	BD	0.325	-
7	71.4	2	62(9)	0.38(0.06)	0.30	0.08
8	68.5	2	BD	BD	0.30	-

Test Period 4 (01/14/87 to 03/30/87--75 days)
Average Outdoor Temperature: 35.7°F

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX ACH	Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)		
1	70.0(f)	2(c)	BD	BD	0.25	-

- (a) Standard deviation.
- (b) Air changes per hour.
- (c) Two sample tubes capped the entire time period to assess cap leakage; no significant leakage of any PFT type noted.
- (d) Bad data.
- (e) Data not available; temperature from Test Period 1 used in analysis.
- (f) Estimate; temperature data missing for last 11 days of test period.

period). The PFT data matrix analysis assumes that the PFT sample tubes were deployed for an identical number of hours in each unit during a test period. This assumption for the Pullman building tests introduces an additional error in the air exchange rate analysis results of $\pm 4\%$. This error is not reflected in the data in Table 4.2.

4.2 SPOKANE BUILDING

The PFT testing in the Spokane building took place from February 11 to March 30, 1987. A single PFT test covering the entire time period (47 days) and two consecutive tests of 23 and 24 days each were conducted in each unit (see Table 2.1).

Each unit was equipped with an AAHX, and the fresh air flow of each AAHX was measured once during the monitoring of this building prior to the first PFT test period. Air flow was measured at each of the two fresh air ducts and at the outside fresh air intake; measurements were taken with the doors and windows closed. It was assumed that the air flows did not vary significantly over several weeks, and therefore the one-time flow measurement data were used for all calculations over the entire period of testing. Because the AAHXs were used infrequently and were not subject to significant filter clogging (nor are the filters replaced frequently), the estimated error in ventilation flow with this assumption is $\pm 3\%$ for the time period of testing, although this error is not shown in the data in Table 4.3. The results of these measurements are shown in Table 4.3.

No attempt was made to balance the AAHXs. The hours of usage of the AAHXs during the PFT measurement periods was calculated from ELCAP monitoring of the time-series AAHX power consumption data. The total fresh air flow measured in each unit was combined with the hours of usage to determine the air exchange rate contribution of the AAHX. The fresh air flow was the measurement used for calculating the mechanical ventilation component.

Three PFT tracer types were deployed in this building: PDCB, PDCH, and PMCH. The PDCB and PMCH sources were manufactured by PNL; the PDCH sources were manufactured by BNL. The PFT sources were placed inside the ELCAP temperature sensor enclosure, so source temperature was known from ELCAP monitoring data. As in the Pullman building, it is recognized that this is

TABLE 4.3. AAHX Air Flow Measurements in the Spokane Building

Unit	Fresh Air Flow (cfm)			Fresh Air Temperature (°F) (a)	Outside Air Intake Flow (cfm)	Outside Temperature (°F)
	Vent #1	Vent #2	Total			
1730	13.3	19.5	32.3	64	27.0	39
1732	10.7	10.1	20.8	64	24.2	39
1734	9.0	20.2	29.2	63	18.5	39

(a) Temperature recorded by the AAHX fresh air temperature sensor.

not the optimum location for PFT sources. However, the mixing in each unit was adequate because the units were small, and mixing was aided by the mechanical ventilation system.

Two side-by-side sample tubes were hung from the ceiling in the kitchen/living area in each unit for each test period. The tubes and sources were deployed at the same time during the first test period.

Table 4.4 summarizes the air exchange rate measurements, mechanical ventilation, and environmental data collected in the Spokane building. Again, the baseline air exchange rate of each unit is calculated by assuming that the air exchange rate from mechanical ventilation is directly additive to the baseline air exchange rate to obtain the total air exchange rate of the unit. Figures 4.4 to 4.6 illustrate the air exchange rate and unit-to-unit air flows (m^3/h) in the building for the three test periods.

4.3 FIFE BUILDING

The Fife building was tested from November 13, 1986, to March 3, 1987. This building underwent the most extensive testing primarily because of the involvement of Tacoma Public Utilities personnel who placed and recovered PFT materials. Every unit in the building received at least two PFT measurements of 33 and 22 days each (see Table 2.1). These were not consecutive test periods because of a decision not to disturb the residents over the holiday period. The four adjacent units with a 6617 address underwent additional tests of 26 and 24 days following the second test, and a long-term test of 110 days began on 11/13/86. Adjacent Units 6619-1 and 6619-3 also had long-term PFT testing for a period of 84 days beginning on 11/13/86. More units were scheduled for short- and long-term testing, but occupants of these units would not allow testing to continue after the first two tests.

Each of the Fife building units had an AAHX, and the air flow at two speeds (high [HI] and low [LO]) was measured prior to the start of the second test period (02/05/87). Measurements were taken with the doors and windows closed; the position of the fireplace damper was not known. Air flow measurements were taken at each of the three fresh air supply ducts and at the outside exhaust duct. Table 4.5 gives the AAHX flows measured in each unit.

TABLE 4.4. Summarized Measurement Data for the Spokane Building

Test Period 1 (02/11/87 to 03/06/87--23 days)

Average Outdoor Temperature: 39.9°F

Average Wind Speed: 1.0 m/s

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Base-line ACH
			Infiltration (m ³ /h)(SD) (a)	ACH(b) (SD)	(h)	ACH	
1730	71.4	2	DL(c)	DL	297	0.18	-
1732	71.2	2	23(5.5)	0.13(0.03)	77	0.03	0.10
1734	71.1	2	32(3)	0.19(0.02)	160	0.08	0.11

Test Period 2 (03/05/87 to 03/30/87--25 days)

Average Outdoor Temperature: 43.2°F

Average Wind Speed: 0.7 m/s

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	(h)	ACH	
1730	72.5	2	85(12)	0.50(0.07)	398(d)	0.21	0.29
1732	71.4	2	21(11)	0.12(0.02)	166	0.06	0.06
1734	62.6	2	17(2)	0.10(0.01)	151(e)	0.08	0.02
Overall Building			127(12)	0.25(0.02)	-	-	-

Test Period 3 (02/11/87 to 03/30/87--47 days)

Average Outdoor Temperature: 41.7°F

Average Wind Speed: 0.9 m/s

Unit	Avg. Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	(h)	ACH	
1730	72.0	2	40(10)	0.235(0.06)	695(d)	0.20	0.035
1732	71.3	2	25(3)	0.14(0.02)	243	0.05	0.09
1734	66.7	2	27(5)	0.16(0.03)	311(e)	0.08	0.08
Overall Building			92(11)	0.18(0.02)	-	-	-

(a) Standard deviation.

(b) Air changes per hour.

(c) Data lost during analysis.

(d) Some AAHX usage monitoring data missing, therefore data estimated for the missing time periods.

(e) Occupant moved on 03/15/87 and unit was vacant for remaining test period.

R9001130.2

FIGURE 4.4. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Spokane Building, Test Period 1 (air flows are shown in bold type)

Spokane Building

R9001130.3

FIGURE 4.5. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m^3/hr) for the Spokane Building, Test Period 2 (air flows are shown in bold type)

Spokane Building

FIGURE 4.6- Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m^3/hr) for the Spokane Building. Test Period 3 (air flows are shown in bold type)

R900130.4

TABLE 4.5. AAHX Air Flow Measurements in the Fife Building

Unit	Fresh Air Flow (cfm)								Temp. (°F) (a)	Exhaust Air		Temp. (°F) (b)
	Vent. #1		Vent. #2		Vent. #3		Total	Flow (cfm)				
	HI	LO	HI	LO	HI	LO				HI	LO	
6617-1	11.5	6.9	14.7	9.1	23.9	14.9	50.1	30.9	70	50.7	31.0	63
6617-2	13.4	9.8	11.4	8.3	22.0	16.1	46.8	34.2	69	50.8	39.0	56
6617-3	12.8	8.2	8.9	5.8	21.7	13.0	43.4	27.0	(c)	49.2	31.3	(c)
6617-4	11.4	7.3	15.6	9.2	21.6	13.3	48.6	29.8	67	49.9	31.6	62
6619-1	13.2	8.4	11.5	7.6	17.9	11.5	42.6	27.5	73	25.5	16.3	66
6619-2	13.8	8.8	10.7	5.7	28.2	17.4	52.7	31.9	63(d)	52.8	30.6	66
6619-3	6.7	5.9	5.8	5.0	11.1	9.8	23.6	20.8	72	NM ^(e)	NM	NM
6619-4	9.7	6.7	16.6	10.7	17.3	11.9	43.6	23.9	73	50.6	33.6	60
6621-1	13.8	7.5	12.4	7.8	26.4	14.5	52.6	29.8	(c)	54.8	31.4	(c)
6621-2	13.9	9.3	14.8	9.5	26.1	17.6	54.8	36.4	(c)	57.1	36.6	(c)
6621-3	7.8	7.2	6.4	5.9	13.2	12.2	27.4	25.3	(c)	63.4	51.4	(c)
6621-4	14.1	8.9	13.8	8.8	15.2	10.0	43.1	27.7	(c)	49.6	30.7	(c)

- (a) Temperature recorded from the AAHX fresh air sensor.
 (b) Temperature recorded from the AAHX exhaust air sensor.
 (c) Temperature not recorded and therefore volumetric flows not temperature corrected. This introduces an additional error of +3% to flow measurements.
 (d) Temperature is correct according to monitoring data. It appears to be low compared to the other units.
 (e) Not measured.

The hours of AAHX usage during the PFT test periods were determined for those units with EICAP metering. It was difficult to distinguish between HI and LO speed operation of the AAHX from the hourly average electricity consumption records. Therefore, it was assumed that the AAHXs were run at the HI speed during any period of operation. This is a "best case" scenario for determining the natural air exchange rate of a unit from the total air exchange rate measurement data.

No records of AAHX usage were kept by occupants of the units without EICAP monitoring (Units 6621-1, 6621-2, and 6621-3). Therefore, no data are available for the AAHX contribution to the total ventilation in these units. Occupants kept no records of wood usage or other activities such as opening of windows during the PFT tests in any unit.

As in the other two buildings, the baseline air exchange rate of each unit is calculated by assuming that the mechanical ventilation is directly additive to the natural air infiltration to obtain the total air exchange rate of the unit.

As in the Pullman building, four PFT tracer types were deployed in the units: PMCP, PDCB, PMCH, and PDCH. All units tested had ELCAP temperature sensors. Four temperature sensors were installed in each unit: one each in the master bedroom, the living room, the AAHX fresh air duct (in the bedroom), and the AAHX exhaust air duct. The PFT sources were located in the living room temperature sensor enclosure for those units with only one source and in both the living room and bedroom temperature sensor enclosures for those units with two sources (see Figure 2.3). The units are relatively small, and it was assumed that PFT tracer mixing was adequate in each unit.

The PFT sample tubes were located in the hallway of each unit unless otherwise noted. The sample tubes were set out within 2 hours and recovered within 2 hours in all units during each test period.

All sources except the PDCH sources were manufactured by PNL. We experienced problems with the PNL-manufactured PDCB and PMCP sources which did not elute detectable quantities of PFT as expected. Therefore, no detectable quantities of PDCB or PMCP (above background levels) were found in the sample tubes during analysis, and the air exchange rate was not determined for the units with PDCB and PMCP sources.

Each unit in the building was treated as a distinct zone. For the PFT multizone analysis, the units were combined based on the length of common wall between units (see Figure 2.3). The PFT data were analyzed using combinations of 2- and 4-units as zones in the following configuration:

- 2-unit configuration: Units 6617-1, 6617-4; and Units 6621-1, 6621-3
- 4-unit configuration: Units 6617-1, 6617-3, 6619-2, 6619-4; and Units 6619-1, 6619-3, 6621-2, 6621-4.

The validity of this configuration was confirmed by examining the flow between units for alternate configurations, noting the magnitude of the flows between units. The air flow patterns are discussed in the analysis for Test Periods #4 and #5 (see Section 5.3.2). The air flows between adjacent units separated by a stairwell and with a short common wall was minimal, less than 2% of the total flow into the units.

Table 4.6 summarizes the air exchange rate measurements, mechanical ventilation, and environmental data collected in the Fife building. Figures 4.7 to 4.12 illustrate the air exchange rate and unit-to-unit air flows (m^3/h) in the building for each of the measurement periods. As noted in Table 4.6, there are significant missing data because of the problems with the PFT sources and the chemical analysis of samples.

4.4 TACOMA BUILDING

The Tacoma building was tested in early 1988, so the experience gained from testing the other buildings was used in this building. A single 15-day measurement was conducted in the building. Four source types were used in the experiment: PMCP, PMCH, o-PDCH, and p-PDCH, all manufactured by BNL.

A minimum of two sources and one sample tube were placed in each unit. Sources were placed in the main living area and in one of the bedrooms. Sample tubes were located in a central location in the main living areas. In Unit 8703-C (see Figure 2.4) two side-by-side sample tubes were deployed; in Unit 8701-D, one sample tube was deployed in the main living area, and one sample tube was placed in the hallway.

The sources and sample tubes were placed simultaneously in each unit, and the sources and sample tubes were placed in all 12 units within a 22 hour time period. The sample tubes were all recovered within 1.5 hours at the end of the monitoring. In the data analysis, it is assumed that the sample tubes have all been exposed for the same time period. The additional error in data analysis introduced by this assumption in this building is $\pm 4\%$; this error is not reflected in the data in Table 4.7.

For the PFT air exchange rate and air flow analyses, the units were combined based on the length of common wall between units (see Figure 2.4). As in the Fife building, the validity of this configuration was confirmed by

TABLE 4.6. Summarized Measurement Data for the Fife Building

Test Period 1 (11/31/86 to 12/16/87--33 days)

Average Outdoor Temperature: 43.2°F

Average Wind Speed: 2.0 m/s

Unit	Average Indoor Temperature (a) (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD) (b)	ACH(c) (SD)	h	ACH	
6617-2	70.5	2	48(5)	0.22(0.03)	0	0	0.22
6617-4	57.6	2	BD(d)	BD	0	0	-
6617-1	73.8	2	51(6)	0.22(0.03)	1	0.001	0.22
6617-3	67.5	2	BD	BD	0	0	-
6619-2	61.3	2	DL(e)	DL	0	0	-
6619-4	76.5	2	BD	BD	2	0.001	-
6619-1	72(f,g)	2(h)	82(12)	0.44(0.07)	0	0	0.44
6619-3	67.3	2	BD	BD	786	0.21	-
6621-2	66(f)	2	37(4)	0.20(0.025)	NM	-	-
6621-4	69(f)	2	BD	BD	0	0	-
6621-1	68.7	2	BD	BD	NM	-	-
6621-3	74.1	2(h)	BD	BD	NM	-	-

Test Period 2 (01/14/87 to 02/05/87--25 days)

Average Outdoor Temperature: 39.8°F

Average Wind Speed: 0.7 m/s

Unit	Average Indoor Temperature (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	h	ACH	
6617-2	72.0	2	139(112)	0.75(0.60)	108	0.09	0.66
6617-4	63.1	3(i)	BD	BD	1	0.001	-
6617-1	75.6	2	168(29)	0.09(0.2)	63	0.055	0.845
6617-3	66.6	2	BD	BD	0	0	-
6619-2	57.9(i)	2	119(13)	0.64(0.08)	0	0	0.64
6619-4	66.7	2	BD	BD	0	0	-
6619-1	71.8	3(h,i)	BD	BD	499	0.37	-
6619-3	67.8	2	BD	BD	523	0.21	-
6621-2	66.4	2	120(42)	0.65(0.22)	NM	-	-
6621-4	68.7	2	BD	BD	2	0.001	-
6621-1	68.1	2	95(10)	0.51(0.06)	NM	-	-
6621-3	73.2	2	BD	BD	NM	-	-

TABLE 4.6. (contd)

Test Period 3 (11/31/86 to 02/05/87--84 days)

Average Outdoor Temperature: 43.7°F

Average Wind Speed: 1.6 m/s

Unit	Average Indoor Tempera- ture (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	h	ACH	
6619-1	71.8	2(h)	201(21)	1.1(0.25)	1475	0.29	1.81
6621-3	73.2	2(h)	BD	BD	NM	-	-

Test Period 4 (02/05/87 to 03/03/87--26 days)

Average Outdoor Temperature: 45.3°F

Average Wind Speed: 1.3 m/s

Unit	Average Indoor Tempera- ture (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	h	ACH	
6617-2	70.0	2	75(12)	0.41(0.07)	49	0.04	0.37
6617-4	63.5	2	BD	BD	0	0	-
6617-1	75.0	2	92(95)	0.49(0.06)	17	0.015	0.475
6617-3	66.6	2	BD	BD	0	0	-

Test Period 5 (03/03/87 to 03/27/87--24 days)

Average Outdoor Temperature: 46.9°F

Average Wind Speed: 1.3 m/s

Unit	Average Indoor Tempera- ture (°F)	#Sample Tubes	PFT-Measured Total		AAHX Contribution		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	h	ACH	
6617-2	69.1	2	70(7)	0.38(0.04)	109	0.09	0.29
6617-4	63.0	2	BD	BD	0	0	-
6617-1	75.4	2	115(12)	0.62(0.07)	70	0.06	0.56
6617-3	67.3	2	BD	BD	0	0	-

TABLE 4.6. (contd)

Test Period 6 (11/13/86 to 03/03/87--110 days)

Average Outdoor Temperature: 43.1°F

Average Wind Speed: 1.65 m/s

Unit	Average Indoor Tempera- ture (°F)	#Sample Tubes	PFT-Measured Total		AAHX		Baseline ACH
			Infiltration (m ³ /h)(SD)	ACH(SD)	Contribution h	ACH	
6617-2	70.9	2	99(10)	0.53(0.06)	109	0.02	0.51
6617-4	62.4(j)	2	BD	BD	53(k)	0.01	-
6617-1	75.4	2	134(13)	0.72(0.1)	172	0.03	0.69
6617-3	66.6	2	BD	BD	0	0	-

- (a) Living area sensor.
 (b) Standard deviation.
 (c) Air changes per hour.
 (d) Bad data.
 (e) Data lost in analysis.
 (f) Missing data, temperature estimated from second test period data.
 (g) Residents moved on 12/02/86 and apartment vacant until 12/30/86.
 (h) One tube hung in hallway and 1 tube hung in dining area.
 (i) One tube capped the entire test period to ascertain cap leakage; analysis showed no significant leakage.
 (j) Residents moved out of unit 5 days before end of test (01/30/87). Unit was vacant and heat turned off for those 5 days.
 (k) AAHX used during time period 12/17/86-01/13/86.

examining the flow between units for alternate configurations and noting the magnitude of the flows. The PFT data were analyzed using a combination of 2- and 4-unit zones in the following configuration:

- 2-unit configuration: Units 8701-A and 8701-C; Units 8705-B and 8705-D
- 4-unit configuration: Units 8701-B, 8701-D, 8703-A, and 8703-C; and Units 8703-B, 8703-D, 8705-A, and 8705-C.

Table 4.7 summarizes the air exchange rate measurements, mechanical ventilation, and environmental data collected in the Tacoma building. The units are grouped according to the selected PFT multizone analysis configuration. The occupants in the Tacoma building were the only occupants asked to keep activity records. The summarized data from those records are also given in Table 4.7.

Fife Building

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FIGURE 4.7. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 1 (air flows are shown in bold type)

Fife Building

R9001130.14

FIGURE 4.8. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 2 (air flows are shown in bold type)

Fife Building

R9001130.18

FIGURE 4.9. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 3 (air flows are shown in bold type)

Fife Building

R9001130.17

FIGURE 4.10. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 4 (air flows are shown in bold type)

Fife Building

R9001130.16

FIGURE 4.11. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 5 (air flows are shown in bold type)

Fife Building

FIGURE 4.12. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Fife Building, Test Period 6 (air flows are shown in bold type)

TABLE 4.7. Summarized Air Exchange Rate and Occupant Activity Data for the Tacoma Building

Test Period: 01/15/88 to 01/30/88--15 days
Average Outdoor Temperature: 41°F
Average Wind Speed: 1.8 m/s

Unit	Avg. Indoor Temperature °F	#Sample Tubes	PFT-Measured Total		Vent Fan Usage (min)	Wood Burned (hr)	Window Open (hr)
			Infiltration m ³ /h (SD)	ACH ^(b) (SD)			
8701-A	68	1	119(17)	0.475(0.07)	22,000	0	0
8701-C	68	1	123(17)	0.47 (0.07)	NR ^(c)	NR	NR
8701-B	71 ^(d)	1	107(15)	0.425(0.06)	320	11	0
8701-D	71 ^(d)	2 ^(e)	84(9)	0.33(0.04)	1,200	0	0.5
8703-A	73 ^(d)	1	65(9)	0.30(0.05)	0	10	10
8703-C	74 ^(d)	2 ^(f)	84(9)	0.37(0.04)	655	14	16
8703-B	68 ^(d)	1	159(23)	0.73(0.11)	650	0	365.5
8703-D	76	1	73(11)	0.32(0.05)	570	0	26
8705-A	71 ^(d)	1	94(14)	0.43(0.07)	190	0	0
8705-C	76	1	176(26)	0.77(0.12)	100	18	16
8705-B	75	1	108(15)	0.43(0.06)	105	0	0
8705-D	67	1	109(16)	0.42(0.06)	125	0	7
Overall Building		13	1302(448)	0.45(0.16)	-	-	-

- (a) Standard deviation; reflects error in analyses only except in Units 8701-D and 8703-C where SD between sample tubes is included in analysis.
(b) Air changes per hour.
(c) Not recorded.
(d) Temperature recorder failed, one-time central living area temperature measurement at start of test.
(e) One sample tube in hallway, one sample tube in living area.
(f) Side-by-side pair of sample tubes.

Figure 4.13 illustrates the air exchange rates and unit-to-unit air flows (m³/h) in the building for the test period. No data are missing, so a complete multizone analysis was possible for this building.

[illegible]

FIGURE 4-13. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m^3/hr) for the Tacoma Building (air flows are shown in bold type)

5.0 DISCUSSION

5.1 GENERAL OBSERVATIONS

The buildings in this study were chosen because they were monitored under the ELCAP, and the owners and managers were cooperative. An insufficient number of successful PFT tests were conducted in the sample to allow quantitative correlations to be performed across the sample. The influence of climate, structure, and occupancy characteristics on air exchange rate cannot be quantified in this project. However, the PFT test data and the ventilation data do have significant value for a general understanding of regional energy-efficient multifamily building construction and ventilation. In addition, the study allows one to evaluate the protocols used in taking measurements and to make recommendations for future studies of this type. Qualitative conclusions and observations can also be made about the buildings and occupant behavior in the multifamily sector.

In the three buildings constructed to the "tight" infiltration package (0.1 ACH natural ventilation) (the Spokane, Pullman, and Fife buildings), the baseline air exchange rate ranged from 0.03 ACH to approximately 1.02 ACH across the sample. Some measurements in the Pullman and Fife buildings indicate that the baseline air exchange rates for some units in these buildings are in the range of 0.7 to 1.0 ACH. Baseline air exchange rate measurements in this range may be inaccurate, considering the construction features of the building and ventilation system capacity and usage. The PFT data from these two buildings are also the most uncertain.

The Spokane data indicate that the natural air exchange rates for the building range from 0.02 to 0.11 ACH. These whole-building data are the most believable gathered from the three "tight package" buildings, primarily because the long-term test data (Test Period #3) correlate reasonably well with data from the two consecutive short-term tests. This building was the only single-story building in the sample, and one would expect lower baseline air exchange rates because of the reduced stack effect in a one-story structure.

The baseline air exchange rate for the Tacoma building cannot be determined directly from data analysis since no ventilation flows were measured, but it is estimated that the baseline air exchange rate is in the range of 0.35 to 0.5 ACH. Because the minimum target baseline air exchange rate for this building is 0.35 ACH, it appears that it was met.

The AAHXs in all the apartments were significantly out of balance. The most extreme example of this imbalance is in the Pullman building. In the 11 units in which the air flow was measured, the fresh air flow was four to five times the stale air return flow. This probably created a positive pressure (compared with the outside) in every unit.

The usage of the mechanical ventilation systems (in those units with occupant control) was very low. The usage of the systems ranged from 0 to 100% of the time during the testing periods, and the mean was approximately 23% of the total hours of testing. The greatest usage in any building was in the Spokane building where the mean usage was 40% over the two test periods. The greatest usage in any single unit was 100% over the test period in Unit 8701-A of the Tacoma building.

5.2 PULLMAN BUILDING

Testing in the Pullman building began on January 31, 1987, and ended on March 30, 1987. During this time, all of the units remained occupied, and there was no occupant turnover. The unusual feature of this building is that it has a central AAHX for the entire building with no occupant control. Therefore, the air exchange rate in the building is dominated by the mechanical ventilation.

5.2.1 Mechanical Ventilation Measurements

The contribution from the mechanical ventilation system in these units ranged from 0 (for the unit with the grills sealed) to 0.325 ACH with a mean contribution of 0.27 ACH. This fresh air flow is not sufficient to maintain the target total air exchange rate of 0.5 ACH if one assumes that the baseline air exchange rate is approximately 0.1 ACH as specified by the target level of the construction code. The system appears to be undersized or in need of maintenance.

The mechanical ventilation system was significantly out of balance in every unit in the building. The stale air return flow ranged from 0 to 27% of the fresh air flow. This resulted in a significant pressurization of each unit (except Unit 11 where the AAHX fresh air grills were sealed). Under these conditions, one would expect very little natural outside air infiltration in the units. Significant air infiltration from an adjacent unit can result from the differences in pressure between adjacent units created by the unbalanced AAHX, combined with the stack effect in the building, but the data were insufficient to draw any definitive conclusions about unit-to-unit air flow.

5.2.2 PFT Measurements

The PFT data show that Units 6 and 10 have high total air exchange rates (0.87 to 1.25 ACH). However, the high air exchange rate does not seem reasonable for these units given their construction and mechanical ventilation and the lifestyles of the students occupying these apartments; therefore, the data are suspect. In the remaining units (Units 2, 9, 11, and 12) total air exchange rates ranged from 0.15 ACH to 0.82 ACH with a mean of 0.44 ± 0.23 ACH for the two test periods when all units were tested. The standard deviation of approximately one-half the mean indicates a significant scatter in the data. For these same five units, the baseline air exchange rate ranges from 0.03 to 0.495 ACH with a mean of 0.20 ± 0.17 . The agreement in analysis between the pair of tubes in those units with usable data is generally good, as the standard deviations recorded in Table 4.2 indicate.

The very low air exchange rate measured in Unit 11 for Test Period 1 is significant. The fresh air grills in this unit were sealed during the testing, and therefore the measured value may be the most representative baseline air exchange rate for a typical unit of this building.

The best unit-to-unit air flow data are for adjacent Units 6, 11, and 12 during Test Period 1. There is significant air flow from the lower two units (11 and 12) to the upper unit (6). This air flow is 50% of the total flow of air into Unit 6 and is indicative of the stack effect acting on this part of the building.

The long-term data (Test Period 4) taken in Unit 1 were unusable. There were insufficient usable data to determine with any certainty the baseline or total air exchange rate for this building.

During Test Periods 1 and 2, when all 12 units were tested, the mean outside temperature was 33.0°F. The Typical Meteorological Year (TMY) outside temperature for a heating season (11/01 to 3/31) is 30.2°F (Spokane data), so these tests were conducted during weather conditions that were within 10% of typical heating season outdoor temperature at this site. The mean inside-outside temperature difference for the time period of Tests 1 and 2 was 38.0°F.

5.2.3 Previous PFT Measurements

The air exchange rate in the Pullman building was previously measured from March 10, 1986 to May 1, 1986 (52 days) under an RSDP evaluation project sponsored by BPA. Only six adjacent units were selected for testing: Units 1, 2, 3, 7, 8, and 9. The results of the previous test are shown in Figure 5.1. Four source types were used: PMCH, PDCH, PDCB and PMCP. The sources were manufactured and the sample tubes analyzed by BNL. It appears that the PDCB tracer did not cause interference problems with the PMCP since all analysis was completed.

The building and unit diagram supplied with the data analysis sheet from BNL indicates that PMCP was the tracer used in zone 1 (Units 1 and 3), and PDCH was the tracer used in zone 4 (Units 7 and 9). The data analysis sheet has these tracers reversed. The air exchange rate data for these zones are not significantly affected by this apparent error, but the zone-to-zone air flow data are affected and probably will change significantly if the error is corrected and the analysis is rerun. The analysis cannot be rerun easily, however, without the raw chemical analysis data, so the results are reported as received from the BNL analysis.

Two sample tubes were placed in Units 2 and 8, and apparently, two were also placed in each of the remaining four units. Units 1 and 3 were combined into a single zone as were Units 7 and 9 by placing the same tracer type in each pair of adjacent units. However, because of this testing protocol (not using unique tracers in adjacent apartments), no distinction can be made

Pullman Building

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FIGURE 5.1. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m³/hr) for the Pullman Building RSDP Evaluation (air flows are shown in bold type)

between the air flows from Units 2 or 8 to any of the adjacent units (1, 3, 7, 9). Also, the air flows between Units 1 and 7 and Units 3 and 9 cannot be ascertained.

The only RSDP PFT data that can be compared with the results from the tests in this study are the mean fresh air exchange rates in individual units. And since no AAHX air flows were recorded for these units in the previous tests, only the total ventilation rates measured can be compared; the mechanical ventilation component cannot be separated.

The mean air exchange rate in the units from the RSDP test was 0.46 ± 0.11 ACH. The data from these same units are insufficient in the current test to make a good comparison with the RSDP test. The agreement in analysis among the sample tubes in the units is difficult to determine since the sample tubes in Units 1 and 3 and in Units 7 and 8 were combined in the analysis. The agreement between the sample tubes in Unit 2 and in Unit 8 was within a 10% standard deviation. It is not clear if the tubes were deployed side-by-side or separated spatially.

The average inside temperature for all units used in the previous PFT analysis was 70.4°F. The average outside temperature during this test period was 44.9°F. The mean TMY heating season outside temperature is 30.2°F for this region, so the temperature during this test period was nearly 50% greater than the TMY temperature for a heating season. The average inside-outside temperature difference during the measurement period was 25.5°F.

5.3 SPOKANE BUILDING

Testing in the Spokane building began on February 2, 1987, and ended on March 30, 1987. During this time, there was occupant turnover as noted in Table 4.4. The following are results from the Spokane building testing.

5.3.1 Mechanical Ventilation Measurements

Based on the one-time air flow measurements, the AAHXs in the apartments will deliver between 0.21 to 0.32 ACH. These apartments were constructed to meet a natural air exchange rate specification of 0.1 ACH. Assuming the

natural air exchange rate is 0.1 ACH, the target total air exchange rate of 0.5 ACH will not be met in any of the units with the ventilation system as installed.

The AAHXs in these units were also out of balance. The measurement data (Table 5.3) indicate that the AAHXs in Units 1730 and 1734 exhausted significantly more air than they drew in from the outside, likely creating a negative pressure in the units. In Unit 1732, the AAHX drew more air than it exhausted, likely creating a positive pressure in the unit.

The mean AAHX usage in the three units was approximately 41% of the time during the two consecutive PFT test periods. The total hours of AAHX use over the test period was 695 hours in Unit 1730 (62% of the occupied time), 243 hours in Unit 1732 (22% of the occupied time), and 311 hours in Unit 1734 (41% of the occupied time). This was the highest usage of mechanical ventilation equipment in any of the buildings where the occupant could control the equipment.

5.3.2 PFT Measurements

The mean total air exchange rate for the building as measured during Test Period 3 is 0.21 ± 0.03 ACH. The total exchange rate ranged from 0.10 to 0.50 ACH for the two test periods. The mean baseline air exchange rate calculated from Test Periods 1 and 2 is 0.12 ± 0.10 ACH, ranging from 0.02 to 0.29 ACH for the two test periods.

The data indicate that the building is very tight; in fact, it is too tight. Considerable condensation was noted on the windows of all three units during the time period of the tests. Icicles also formed on the outside of the windows, apparently from moisture migrating to the outside of the structure at the windows. The usage of the AAHXs in the units did not successfully mitigate this moisture problem. Significant damage to the structure is likely if this condition persists.

The greatest mean air exchange rate over the two test periods was measured in Unit 1730. This unit was the most exposed of the three units

(see Figure 2.2), and the occupant of this unit also used the AAHX the greatest number of hours during the measurements.

The flow of air between adjacent units ranged from <1% to 16% of the total air flow into the units. This was considerably less than the unit-to-unit flow measured in any of the other three buildings, probably because the building is a one-story structure (no second floor units to enhance the stack effect), and the shell appears to be tight.

The data from the long-term PFT test agreed reasonably well (within the standard deviation) with the two short-term tests in Units 1732 and 1734 considering the usage of the AAHX (see Section 6.1.3). The mean air exchange rate in Unit 1732 for the two short-term tests was 0.125 ± 0.007 ACH compared with 0.14 ± 0.02 ACH for the long-term test; in Unit 1734, the short-term mean air exchange rate was 0.145 ± 0.06 ACH compared to 0.16 ± 0.03 ACH for the long-term test.

During the two testing periods, the mean inside temperature of the building was 71.5°F (not counting the time that Unit 1734 was vacant). The mean outdoor temperature was 41.7°F, and the mean windspeed was 0.9 m/s. This compares to the mean TMY heating season outside temperature of 30.2°F and windspeed of 4.5 m/s (Spokane airport data). The airport TMY windspeed data is equivalent to approximately 1 m/s at the site when the correction is applied for instrument altitude and terrain. The mean windspeed during the time of the test was within 10% of the mean TMY windspeed, but the mean outdoor temperature during the tests was 38% higher than the TMY heating season temperature. This significant difference in heating season temperature could result in a lower natural air exchange rate for this measurement period because the indoor-outdoor temperature driving force of air infiltration was less than that of a typical heating season.

5.3.3 Previous PFT Measurements

The ventilation rate in the Spokane building was measured using the PFT technique from March 11, 1986, to May 1, 1986 (51 days), under the RSDP evaluation program. The three source types used were PMCP, PMCH, and PDCH, all supplied by BNL. Two sample tubes were placed in each of the three units. The results of the test are illustrated in Figure 5.2. No measure of

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FIGURE 5.2. Air Exchange Rates (air changes/hr) and Unit-to-Unit Air Flows (m^3/hr) for the Spokane Building RSDP Evaluation (air flows are shown in bold type)

the air flow or contribution from the AAHX in each unit was recorded in the available RSDP evaluation data; therefore, only the total air exchange rate in each unit can be discussed.

The mean air exchange rate for the building during the previous (RSDP) study was 0.053 ± 0.005 ACH. This compares with a mean air exchange rate for the current measurements of 0.21 ± 0.03 ACH, approximately a factor of five greater. The very low air exchange rate for the previous evaluation indicates that there was probably little or no usage of the AAHX in any unit, and/or one or all of the units were unoccupied during a significant portion of the test period. No occupancy data were available.

The average inside temperature used for the RSDP PFT analysis was 70.4°F for Unit 1732 and 60.4°F for Units 1730 and 1734. The average outdoor temperature during the test period was 44.9°F or approximately 49% greater than the TMY heating season temperature. The mean inside-outside temperature difference was 22.2°F during the RSDP evaluation. The low inside-outside temperature difference also may have contributed to the very low air exchange rates measured in the RSDP test.

5.4 FIFE BUILDING

The most extensive PFT testing was done in the Fife building primarily because of the cooperation of the manager and the availability of Tacoma Public Utilities personnel to assist in the placement and recovery of PFT materials. The testing began on November 31, 1986, and did not end until March 27, 1987. During the testing period, most of the units remained occupied with little turnover in occupants.

5.4.1 Mechanical Ventilation Measurements

According to information from the one-time measurement of flow (see Table 5.5), the air exchange rate contribution from the AAHXs in the 12 units ranged from 0.21 to 0.50 ACH at the high speed setting. The mean AAHX contribution was 0.37 ± 0.10 ACH. The flow measurements indicate that the AAHXs, as installed, contribute the required fresh air exchange rate to meet code in all but two of the units (Units 6619-3 and 6621-3).

In the 9 units with AAHX time series usage data, the mean usage of the AAHX during the Test Periods 1 and 2 (when all 9 units were tested) was approximately 17% of the time; the range was from 0 to 94%. Excluding the high usage in two of the units (Units 6619-3 and 6619-1), the AAHXs were used less than 2% of the time period in the remaining 7 units. The total unit-hours of usage of the AAHXs nearly doubled from the first test period (789 unit-hours) to the second test period (1194 unit-hours). This increase may be attributable to the air flow measurement conducted in each unit at the start of second PFT test period. Residents became curious about the operation, purpose, and maintenance of the AAHXs as the air flows were being measured and apparently decided to use them.

The unit with the greatest percent usage of the AAHX during the testing (Unit 6619-3) was also one of the two units in which the AAHX flow at high speed was relatively low (0.24 ACH). The high usage of the AAHX and low air flow suggest that the filters may have been clogged during the measurement period.

5.4.2 PFT Measurements

The results from PFT measurements in the Fife building were the most disappointing of the four buildings measured, considering the number of measurements made. PFT chemical analysis data were lost for all of the upper units in the building which contained the PDCB and PMCP tracers. In addition to the tracer problems, there were significant quantities of water found in the samples during the analysis. This water was not completely removed prior to the analysis of the PFT, and the water vapor peak appeared at approximately the same time as the PDCB and PMCP peaks. The combination of a relatively low amount of PMCP PFT captured by the sample tubes, the interference with PDCB, and the high water content in the sample tubes caused the PDCB, PMCP, and water peaks to be indistinguishable from one another.

Besides the lost data, the PFT analysis data for the PFT type in Unit 6621-1 was nonsense. The PFT analysis in this unit for Test Periods 1 and 2 gave air exchange rates of 5 and 8 ACH, respectively. Therefore, this unit was not included in the analysis. A source with a nonconstant and/or low emission rate is thought to be the problem in this unit.

The mean short-term total air exchange rate in those units with valid data for the short-term Test Periods 1, 2, 4, and 5 (13 measurements) was 0.49 ± 0.21 . This mean included the data from Unit 6619-2, where residents moved out prior to the end of Test Period 2. The mean was greater than twice the standard deviation. This statistic appears commonly in PFT air exchange measurements for site-built homes (DOE 1988; Parker et al. 1989a). It indicates that the air exchange rate is highly variable and not well-understood, even in like-constructed apartments in the same building.

The mean baseline air exchange rate for those units where the AAHX usage data were available was 0.47 ± 0.21 . This rate was nearly identical to the mean total air exchange rate. This is not surprising since the usage of the AAHX in these units ranged from 0 to 10% of the cumulative time period of the measurements, and therefore one would expect the baseline air exchange rate to be similar to the total air exchange rate in these units. In Units 6617-1 and 2, the AAHX was essentially not used during Test Period 1 (except for 1 hour in Unit 7716-1). The mean baseline air exchange rate in these units was 0.22 ACH. This air exchange rate may be representative of the natural air exchange rate for the building, but the data are inconclusive.

The data from the long-term test in Units 6617-1 and 2 (Tests Period 6) corresponded fairly well with the mean of the consecutive short-term tests. The mean total air exchange rate for Unit 6617-1 for Test Periods 1, 2, 4, and 5 was 0.56 ± 0.28 ACH, compared to a long-term mean of 0.72 ± 0.1 ACH. The two values are the same within the standard deviation. The mean total air exchange rate for Unit 6617-2 for the same test period is 0.44 ± 0.22 ACH; this compares to a long-term mean of 0.53 ± 0.06 ACH. Again, the two values agree within the standard deviation. The means of the short-term tests do not include a test period from 12/16/86 to 01/14/87 which may account for the disparity between mean air exchange rates. The measurement bias associated with long term PFT measurements may also have affected the agreements between the long-term and short-term tests.

Very little data are available to determine the magnitude of the air flow between units. No PFT data are available for the upper floor units, so data for determining flow between floors are unavailable. The data for Test

Periods 1 and 2 showed very little flow between those adjacent units for which there are good data. The air flow ranges are from 0.7 to 7.0 m³/h for units with a long common wall. In Test Periods 1, 4, and 5, the flow between adjacent Units 6617-1 and 6617-2 (with a shorter common wall) was minimal, ranging from 0.1 to 3.6 m³/h.

The mean building indoor temperature during Test Periods 1 and 2 was 68.4°F. The mean outdoor temperature during these test periods was 43.1°F, and the mean wind speed was 1.6 m/s. The mean TMY outdoor temperature from the Seattle airport is 41.7°F and mean TMY wind speed is 4.6 m/s (at the airport). The airport wind speed is equivalent to approximately 1.5 m/s at the Fife building. Therefore, the weather conditions during the testing were nearly equivalent to the TMY conditions for a heating season.

5.5 TACOMA BUILDING

The air exchange rate data from this building were the best data obtained in this project, primarily because the correct PFT tracers were used, and the experience gained performing tests on the three previous buildings was applied.

5.5.1 Mechanical Ventilation Measurements

Most occupants rarely used their ventilation exhaust fans, according to the occupant activity records (see Appendix B). The occupants of 11 units with activity records used their ventilation system a total of 432 hours during the 4026 unit-hours of testing, or about 11% of the time. If the usage of the ventilation system in Unit 8701-A is excluded, the total usage in the remaining 10 units is reduced to less than 2% of the time.

In the one unit (Unit 8701-A), with continuous usage of a single vent fan ("humidistat always set at 40") the results showed the air exchange rate (0.54 ACH) was only slightly above the building mean (0.46 ACH) and well within the standard deviation. This was surprising given the rated air flow of the fan (80 cfm) and the number of hours of usage. The estimated air exchange rate in this unit from usage of a single vent fan (based on an 80 cfm flow) is 0.54 ACH. Since the estimated mechanical component and the total air exchange rate measured with the PFT are the same, there is either a

lack of natural infiltration or other ventilation in the unit (besides the single vent fan), or the actual flow rate of the fan is less than the rating. It is more likely that the flow rate of the fan is less than its rating, but no flow measurements were taken.

5.5.2 PFT Measurements

The mean air exchange rate of the Tacoma building was 0.45 ± 0.16 ACH. This rate is similar to the mean air exchange rate of 0.40 ± 0.19 ACH for 137 single-family homes (non-MCS) built in the region since 1980 (Parker et al. 1989a). The total air exchange rates ranged from 0.30 to 0.77 ACH. The standard deviation of nearly one-half the mean for Tacoma building total air exchange rate is similar to the standard deviation of about one-half the mean found in the single family sample. This observation is important, though not surprising. Although all of the apartments tested were located in the same building, equipped with the same heating system, and built with nearly the same size and geometry, the standard deviation is still fairly significant when compared to the mean value. The single-family structures were of various ages, sizes, and architecture, were built in various locations, and would be more likely to have a significant variation in air exchange rate. This comparison suggests that occupancy, and the occupant's usage of the mechanical ventilation systems, may have the greatest influence on a building's air exchange rate even in nearly identical structures.

Even though occupant activities records were kept for this test, the influence of the occupant's behavior on the air exchange rate is difficult to quantify. For example, the air exchange rates in Units 8703-B (0.73 ACH) and 8705-C (0.77 ACH) are elevated compared with the other 10 units and are primary contributors to the high standard deviation. The air exchange rate in Unit 8703-B can probably be explained by the number of continuous hours that the windows were open (all day every day). An elevated inside-outside temperature difference which occurs overnight when the windows are open creates an elevated air exchange rate. Occupants of other units indicated that their windows were open a significant number of hours, but the time of day was not recorded. One may infer, however, that the windows may not have been open overnight, since none of the apartments recorded more than 3 hours that their windows were open during a single day.

There was no good explanation for the high air exchange rate in Unit 8705-C other than the combination of open windows and fireplace usage (wood burned). The daily records showed that there were several days that the windows were open and the fireplace was used. One could again infer that these activities occurred simultaneously (the room probably got too hot!), and the high inside-outside temperature difference combined with the combustion air requirements of the fireplace elevated the air exchange rate. This is another example of significant occupant influence.

The air exchange rate contribution from the usage of the mechanical ventilation equipment was not quantified for this building; therefore, the baseline air exchange rate cannot be computed for the units with significant usage of the AAHXs. The air exchange rates measured in Units 8710-B, 8701-C, 8703-A, 8701-D, 8705-A, 8705-B, and 8705-D, in which the AAHXs were not used more than 10% of the time, the windows were not opened, and wood was not burned a significant number of hours (combination of hours <5% of the time period), ranged from 0.35 to 0.51 ACH with a mean of 0.43 ± 0.07 ACH. This value is close to the building mean air exchange rate, but it has a significantly lower standard deviation.

In Unit 8701-D, one of the sample tubes was placed in the dining area and the other in the hallway (20 feet apart). The chemical analysis showed close correspondence between the sample tubes for the PMCH PFT type (mean of 94.3 ± 1.2 pL). This correspondence indicates good mixing within the unit. However, there was a larger standard deviation in the analysis for the other three PFT types found on the two tubes. These are PMCP 7.45 ± 0.94 pL; o-PDCH 0.24 ± 0.11 pL; and p-PDCH 8.72 ± 1.1 pL. Though not conclusive, this difference in the standard deviations may indicate the difference in the pathways (airflow patterns) that the air (tagged with the PFT type in a unit) follows as it "migrates" between adjacent units. Additional measurements using several tubes spread throughout a unit would be necessary to draw definitive conclusions about this theory. In the other unit with side-by-side tubes (Unit 8703-C), the standard deviation for all four PFT types found in the tubes was maximum of $\pm 4\%$. This shows excellent agreement in PFT capture among the four tubes.

The air exchange rate was almost the same in the combined upper units (0.45 ACH) as it was in the lower units (0.465 ACH). The direction of the overall total building air flow was primarily from the lower units to the upper units. Most air flow between individual units was from the lower unit to the unit directly above. These air flows ranged from 2 to 29 m³/h. Air flow from the upper units to the lower units was an order of magnitude less, ranging from 0.1 to 1.2 m³/h. Total air flow between units (in any direction) ranged from 0 to 44 m³/h. Air flow between units contributed <1% to 26% of the total air flow into the units, with a mean of 12%. In one of the four zone configurations, the greatest air flow was from the lower unit (Unit 8703-B) to the unit which was adjacent to the unit directly above it (Unit 8705-C). It is quite unusual for the air flow to be so great into a unit with a very limited common wall (surface) area, but the air flow was nevertheless from a lower to an upper unit.

The air flow patterns within the building are patterns one would expect for a building of this size and type. The overall building and unit baseline air exchange rates exceed the target minimum of 0.35 ACH required by the Tacoma Energy Code. The units and the building are somewhat "leakier" than anticipated given the construction standards. However, additional measurements, including ventilation system air flow and usage, would be required to draw definitive conclusions about ventilation in this building.

During the test period the mean outside temperature was 41°F, the mean inside-outside temperature difference was 30.5°F, and the mean wind speed was 1.8 m/s. The mean TMY heating season outdoor temperature is 41°F, and the mean TMY wind speed is 1.5 m/s (Tacoma building site equivalent). Therefore, this test was conducted during weather conditions that are very similar to those of typical heating season conditions at this site.

Considering the difficulty of taking multizone measurements and working in an occupied multifamily building, these data may be the best that one can expect to acquire without additional monitoring (for example, recording real-time airflow data for the ventilation system).

6.0 CONCLUSIONS

Measuring and understanding ventilation in the multifamily sector are very complex. Each building tested in this study is unique in its architecture, construction, and ventilation equipment. Each building has occupants with a wide variety of living habits, and, unlike the single-family sector, there are adjacent living units which greatly influence the living environment; the living units in a multifamily building cannot operate in an environment totally independent from one another. For these reasons, ventilation monitoring studies (or any study) in occupied multifamily units take careful planning and execution.

6.1 LESSONS LEARNED

This study, though small in number of buildings tested, has created an opportunity to learn techniques and protocols for conducting a successful ventilation monitoring study. These lessons are identified below and should be considered for incorporation into any future studies of this type.

6.1.1 Sample Selection

The best sample to represent a sector (single-family or multifamily) or a region is one that has been chosen randomly. A random sample reduces the possibility of biases and lends scientific credibility to the study. If random sampling is not possible because of budget limitations or other restrictions, the next best approach is use of a weighting scheme to minimize potential biases. A sample that is not drawn randomly or that is too small to be weighted should be broken down into individual case studies.

The sample in this study was highly selective and was probably biased. Buildings were selected that had received ELCAP monitoring equipment as part of the RSDP. The ELCAP buildings in the RSDP were all located in the state of Washington and were selected for ELCAP monitoring because their builders volunteered to participate in the demonstration program. The multifamily buildings in Fife and Tacoma were not part of the RSDP and were constructed to standards of the Tacoma Energy Code which are similar to the MCS. These buildings were also selected because the builders were willing to

participate. Though the building architecture in this sample may be typical of energy-efficient multifamily buildings in the region, the sample is not large enough to be representative of the spectrum of building codes and practices one encounters in the region.

6.1.2 Recruiting

Recruiting multifamily occupants to participate in any study should be coordinated with the manager of the apartment complex. This is especially critical if a signed access agreement is necessary, because occupants cannot be relied upon to read explanation materials and return signed agreements promptly on their own.

It is also important that the researchers conducting the study explain, in person, the steps in and important aspects of the study to the occupants. The manager of the apartments should be present during this meeting. The manager can act as a go-between for the occupants and the researcher and can supply current information on occupant turnover. A study cannot be conducted efficiently and successfully without the participation of the building manager.

6.1.3 Field Measurements

The initial placement of materials for ventilation measurements should be made in the presence of all the occupants in an apartment and the manager if possible. If placement is done in their presence, all occupants will be aware that the test is being done, and they can ask questions to gain a better understanding of the purpose and function of the measurement equipment. Subsequent or repeated testing does not necessarily need to be done in the presence of the occupants. However, placement and recovery of materials may need to be done in the presence of the manager.

Occupant activity records are valuable for understanding ventilation and should be included in any ventilation study, even if the mechanical ventilation system activation is monitored (as it is in an ELCAP building). The importance of estimating activities should be carefully explained to all occupants during the initial placement of monitoring equipment. The explanation should not be left to the manager.

Buildings with more than four adjacent units should be tested using six unique PFT types if they are available. With six PFT types, one can distinguish the air flow from all adjacent units. Adjacent units should not contain both PDCB and PMCP because of the interference between these two PFTs during chemical analysis.

Sample tubes should be placed and recovered in all the units in a building during the same day, preferably within a few hours of each other. This will reduce the error in the matrix solution program which assumes that all tubes in multizone analysis have equal exposure time. A test no longer than 2 to 4 weeks should be conducted, especially in buildings with occupant-controlled mechanical ventilation systems. A short measurement period reduces the error (bias) associated with PFT measurements in units with a wide diurnal fluctuation in air exchange rates over the measurement period.

Actual PFT source temperature should be recorded to reduce the error associated with assuming a source temperature for the test period based on a one-time measurement. If source temperature is not available, then actual recorded mean temperature for the whole unit should be used in the analysis.

Standard protocol for single family homes should be followed for source and sample tube placement in multifamily units (Parker et al. 1989a). This protocol includes the deployment of at least two sample tubes per zone, reducing the potential for losing the data from an entire unit or zone if the data from one tube are lost.

A good protocol and accurate instrumentation is needed to measure air flow from mechanical ventilation equipment. This air flow should be measured at least twice at each accessible grill/duct, both inside and outside. These measurements will help determine system balance as well as air flow. Volumetric flows should be corrected for pressure drop and temperature.

If executed properly, the multiple PFT technique is the most appropriate method for determining the total air exchange rate in a multifamily building. The multiple tracer technique is the only way to quantify the air flow between units or zones of a multifamily building. If mechanical ventilation is used in the units, the amount of time the equipment is on as well as air flows of the equipment should be recorded.

6.2 COSTS

The cost to perform a PFT measurement in four adjacent apartments in a building that has been selected and recruited was approximately \$400 to \$700 in this study. Costs included the labor to set out the PFT sources and sample tubes and the PFT analysis. This cost assumes that a pair of sample tubes are deployed in each unit and that the occupants return the exposed tubes and sources in the mail for analysis.

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APPENDIX A

FORMS

Air Exchange Rate Field Study
ACCESS AGREEMENT
(MULTIFAMILY - TENANT)

THIS COOPERATIVE AGREEMENT is made between the PACIFIC NORTHWEST LABORATORIES, BATTELLE MEMORIAL INSTITUTE, (Battelle) and _____ (Tenant), residing at _____, Unit _____, in the City of _____.

In the performance of its Prime Contract DE-AC06-76RLO 1830 with the United States Department of Energy (DOE) Battelle is conducting a research project to measure the ventilation rate in residential buildings in the Bonneville Power Administration (BPA) service region. The results will be used for predicting the average seasonal fresh air exchange rates in residential buildings.

- A. Tenant hereby agrees to permit Battelle and its authorized representatives to:
1. Take a one-time measurement of the flow rate of the fresh ventilation air supplied by the air-to-air heat exchanger to the apartment indicated above.
 2. Place a non-mechanical (silent) ventilation measurement kit in the apartment indicated above for a period of 3-6 weeks.
- B. Project activities are subject to the following conditions:
1. Apartment entry will be required on or after _____.
 2. Entry for ventilation flow measurement and ventilation kit installation and removal will be made only with prior arrangement with the Tenant at least 24 hours in advance. Activities will be accomplished so as not to interfere unduly with Tenant's normal activities.
 3. Tenant agrees not to disturb the ventilation measurement kit in any way, unless authorized by Battelle or as may become necessary for safety.
 4. Tenant agrees to notify Battelle if the Tenant moves during the testing period.
 5. Battelle will not publicize Tenant's participation in the project. All data gathered becomes the property of DOE.
 6. Tenant shall not use Battelle's name or identifying characteristics for advertising, sales promotion or other publicity purpose.
- C. Either party may terminate this Agreement by providing thirty (30) days' written advance notice to the other party.

Both Parties agree that there are no other agreements, express or implied, which are not contained in this Cooperative Agreement.

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES

(Tenant - Print Name)

By _____
Cheryl L. Nickola
Subcontract Specialist
Major Programs, Subcontracts

Signature _____

Phone # _____

Date _____

Date _____

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of _____	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. <i>Hours of Woodstove Use</i>							
2. <i>Hours of Fireplace Use</i>							
3. <i>Hours of Opened Windows</i>							
4. <i>Minutes of all Exhaust Fan Use:</i>							
5. <i>Minutes of Clothes Dryer Use (inside home only)</i>							
6. <i>Unusual Events (Place number under appropriate day and indicate below the event and its impact)</i>	1.						

(Example: 1. Party with several guests.)

APPENDIX B

OCCUPANT ACTIVITY RECORDS
FOR THE TACOMA BUILDING

8701 A

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of	Mon	Tue	Wed	Thur	Fri	Sat	Sun
<u>1/11-17</u>							
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:							
5. Minutes of Clothes Dryer Use (inside home only)							
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use			/				
2. Hours of Fireplace Use	/	/	/				
3. Hours of Opened Windows		14 min 8 hr 12 hr 30 min					
4. Minutes of all Exhaust Fan Use:		1 hr 10 min	1 hr 10 min	1 hr 10 min	1 hr 10 min	1 hr 10 min	
5. Minutes of Clothes Dryer Use (inside home only)	/	/	/			3 hr	1 hr
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.	2 hr 10 min 1 hr 10 min 1 hr 10 min					

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:	<i>Exhaust fan started on 1/25</i>						
5. Minutes of Clothes Dryer Use (inside home only)	<i>1 1/2</i>						
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	<i>1.</i>						

(Example: 1. Party with several guests.)

8701 B

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/11-17</u>	<u>1/15</u> Mon	<u>1/16</u> Tue	<u>1/17</u> Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use					2	1	
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:					180	60	
5. Minutes of Clothes Dryer Use (inside home only)					60	60	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1, Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use		1			2		
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:		40			10		
5. Minutes of Clothes Dryer Use (inside home only)		60		20	45	60	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25-1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use		7			3		
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:			30				
5. Minutes of Clothes Dryer Use (inside home only)		60		60	60		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8701 0

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/11-17</u>	<u>1/15</u> Mon	<u>1/16</u> Tue	<u>1/17</u> Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows						5	
4. Minutes of all Exhaust Fan Use:					30	60	45
5. Minutes of Clothes Dryer Use (inside home only)					120 minutes	5 minutes	120 minutes
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.) 1/16 - Acimate moving in. Saturday day 1/16 - 120 (120 minutes) in kitchen and living room. However we have been asked to keep it private of others.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:	50 min	45 min			40 min	45 min	20 min
5. Minutes of Clothes Dryer Use (inside home only)	160 minutes		60 min	30 min	—	120 minutes	60 minutes
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

Exhaust 30,000 ft³
Dryer

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:	30 minutes	50 minutes	10 minutes	10 minutes	60 minutes	45 minutes	
5. Minutes of Clothes Dryer Use (inside home only)	20 minutes		60 minutes	60 minutes	120 minutes		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8703 A

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

1/15 1/16 1/17

Week of <u>1/11-17</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use					Ø	Ø	Ø
2. Hours of Fireplace Use					3 hrs	Ø	Ø
3. Hours of Opened Windows					1 hr	1 hr	1 hr
4. Minutes of all Exhaust Fan Use:					Ø	Ø	Ø
5. Minutes of Clothes Dryer Use (inside home only)					2 hrs	1 hr	1 hr
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.				Ø	Ø	Ø

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	0	0	0	0	0	0	0
2. Hours of Fireplace Use	0	0	0	0	0	3 hrs	0
3. Hours of Opened Windows	4 hr	0	0	0	1 hr	1 hr	1 hr
4. Minutes of all Exhaust Fan Use:	0	0	0	0	0	0	0
5. Minutes of Clothes Dryer Use (inside home only)	0	1 hr	0	1 hr	1 hr	0	0
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.	0	0	0	0	0	0

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/29 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	Ø	Ø	Ø	Ø	Ø	Ø	Ø
2. Hours of Fireplace Use	Ø	Ø	Ø	Ø	4hrs	Ø	Ø
3. Hours of Opened Windows	1hr	Ø	Ø	Ø	1hr	Ø	1hr
4. Minutes of all Exhaust Fan Use:	Ø	Ø	Ø	Ø	Ø	Ø	Ø
5. Minutes of Clothes Dryer Use (inside home only)	1hr	1hr	Ø	Ø	Ø	1hr	Ø
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.	Ø	Ø	Ø	Ø	Ø	Ø

(Example: 1. Party with several guests.)

8703 B

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

1/15 1/16 1/17

Week of <u>1/11-17</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use					X	X	X
2. Hours of Fireplace Use					X	X	X
3. Hours of Opened Windows					Bedrooms at all times	Bedrooms at all times	Bedrooms all day
4. Minutes of all Exhaust Fan Use:					1 Hour	40 minutes	40 minutes
5. Minutes of Clothes Dryer Use (inside home only)					X	X	X
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.				X	X	X

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

	1/18	1/19	1/20	1/21	1/22	1/23	1/24
Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	X	X	X	X	X	X	X
2. Hours of Fireplace Use	X	X	X	X	X	X	X
3. Hours of Opened Windows	Bedroom all Day	B.R. all day do Patio 20 min	B.R. all day do Patio 15-30 min	B.R. all day do Patio 15-30 min	B.R.'s all day	B.R.'s all day	B.R.'s all day
4. Minutes of all Exhaust Fan Use:	40 minutes	40 min	1 hour	40 min	40 min	40 min	1 hour
5. Minutes of Clothes Dryer Use (inside home only)	2 hours	45 minutes	40-45 minutes	1 hour	X	45 min	X
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1. X	X	X	X	X	X	1. Birthday Party approx 8 guests

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing:

	1/25	1/26	1/27	1/28	1/29	1/30	1/31
Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	X	X	X	X	X	X	X
2. Hours of Fireplace Use	X	X	X	X	X	X	X
3. Hours of Opened Windows	B.R.S all day	Patio 15 min B.R.S all day	B.R.S all day	B.R.S all day	B.R. all day Patio 2 hours	B.R. all day	
4. Minutes of all Exhaust Fan Use:	30 min	40 min	40 min	40 min	40 minutes		
5. Minutes of Clothes Dryer Use (inside home only)	X	3 1/2 hours	X	X	1 1/2 hours	X	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1X	X	X	X	X		

(Example: 1. Party with several guests.)

8703 C

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/11-17</u>	<u>1/15</u> Mon	<u>1/16</u> Tue	<u>1/17</u> Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use						2 hrs	30 min
2. Hours of Fireplace Use							
3. Hours of Opened Windows							1/2 hr
4. Minutes of all Exhaust Fan Use:						35 min	
5. Minutes of Clothes Dryer Use (inside home only)						1/2 hr	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

	1/18	1/19	1/20	1/21	1/22	1/23	1/24
Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	45 min	45 min	30 min	45 min	1 1/2 hr	1 1/2 hr	1 1/2 hr
2. Hours of Fireplace Use			/				
3. Hours of Opened Windows			/	3 hr		1 1/2 hr	2 hr
4. Minutes of all Exhaust Fan Use:	15 min	10 min	60 min	60 min	75 min	45 min	25 min
5. Minutes of Clothes Dryer Use (inside home only)	45 min	60 min	45 min		60 min	10 min	/
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	2 1/2 hr	1 hr	1 1/2	1 hr	1 1/2		
2. Hours of Fireplace Use							
3. Hours of Opened Windows	1 hr		2 1/2 hr	3 hr	3 1/2 hr		
4. Minutes of all Exhaust Fan Use:	15 min	45 min	2 hr	1 hr	15 min		
5. Minutes of Clothes Dryer Use (inside home only)	60 min	30 min		60 min	60 min		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8703 D

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

1/15 1/16 1/17

Week of <u>1/11-17</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							6 hours
4. Minutes of all Exhaust Fan Use:					60 mins		60 mins
5. Minutes of Clothes Dryer Use (inside home only)					2 hours 120 mins		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows						12 hours	
4. Minutes of all Exhaust Fan Use:	120 mins	10 mins	30 mins	30 mins			
5. Minutes of Clothes Dryer Use (inside home only)	120 mins			240 mins	60 mins	120 mins	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.			1			

(Example: 1. Party with several guests.)

1. Baby sat for two more small children.

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows				8.00 am			
4. Minutes of all Exhaust Fan Use:			60	120			
5. Minutes of Clothes Dryer Use (inside home only)	120			60			
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8705 A

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/11-17</u>	<u>1/15</u>	<u>1/16</u>	<u>1/17</u>				
	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use					—	—	—
3. Hours of Opened Windows					—	—	—
4. Minutes of all Exhaust Fan Use:						20 min	20 min
5. Minutes of Clothes Dryer Use (inside home only)					—	—	—
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

I had nine guests on
Sunday, 17

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:		10	10	10	10	10	
5. Minutes of Clothes Dryer Use (inside home only)		10				10	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

Party with several guests

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:	10 <i>minute</i>	10 <i>minute</i>	10 <i>minute</i>	10 <i>minute</i>	10 <i>minute</i>	10 <i>minute</i>	10 <i>minute</i>
5. Minutes of Clothes Dryer Use (inside home only)	30 <i>minute</i>			30 <i>minute</i>			
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8705 B

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/11-17</u>	<u>1/15</u>	<u>1/16</u>	<u>1/17</u>
	Mon	Tue	Wed
1. Hours of Woodstove Use			
2. Hours of Fireplace Use			
3. Hours of Opened Windows			
4. Minutes of all Exhaust Fan Use:			
5. Minutes of Clothes Dryer Use (inside home only)			
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.		2

(Example: 1. Party with several guests.)

2. Packer brought furniture from Ft. Bliss
they took about a hour and half.

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	0	0	0	0	0	0	0
2. Hours of Fireplace Use	0	0	0	0	0	0	0
3. Hours of Opened Windows	0	0	0	0	0	0	0
4. Minutes of all Exhaust Fan Use:	5	0	5	5	5	10	10
5. Minutes of Clothes Dryer Use (inside home only)	0	0	60	0	60	0	60
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

1. DACKER brought the rest of the furniture from Germany

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	0	0	0	0	0		
2. Hours of Fireplace Use	0	0	0	0	0		
3. Hours of Opened Windows	0	0	0	0	0		
4. Minutes of all Exhaust Fan Use:	10	10	10	10	10		
5. Minutes of Clothes Dryer Use (inside home only)	120	30	0	60	30		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8705 C

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

1/15 1/16 1/17

Week of <u>1/11-17</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							4 hrs
3. Hours of Opened Windows						6 hrs	3 hrs
4. Minutes of all Exhaust Fan Use:						20 min.	
5. Minutes of Clothes Dryer Use (inside home only)						2 hrs	
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use	5 hrs	2 hrs	1 hr	1 hr	2 hr	1 hr	1 hr
3. Hours of Opened Windows		1 hr		3 hrs			
4. Minutes of all Exhaust Fan Use:	20 min	10 min	10 min	20 min			
5. Minutes of Clothes Dryer Use (inside home only)	1 hr	2 hrs		2 hrs		1 hr	1 hr
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use							
2. Hours of Fireplace Use							
3. Hours of Opened Windows	03 hrs						
4. Minutes of all Exhaust Fan Use:	20 min						
5. Minutes of Clothes Dryer Use (inside home only)	2 hrs				3 hrs		
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

8705 D

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

1/15 1/16 1/17

Week of <u>1/11-17</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use					0	0	0
2. Hours of Fireplace Use					"	"	"
3. Hours of Opened Windows					1	1	1
4. Minutes of all Exhaust Fan Use:					10	10	30
5. Minutes of Clothes Dryer Use (inside home only)					60	40	35
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/18 - 1/24</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	0	0	0	0	0	0	0
2. Hours of Fireplace Use	0	0	0	0	0	0	0
3. Hours of Opened Windows	0	1	1	1	0	0	1
4. Minutes of all Exhaust Fan Use:	0	0	30	12	20	0	15
5. Minutes of Clothes Dryer Use (inside home only)	120	0	70	0	15	0	100
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

OCCUPANT ACTIVITIES RECORD

Please record the following events on a daily basis each week of PFT testing.

Week of <u>1/25 - 1/31</u>	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1. Hours of Woodstove Use	0	0					
2. Hours of Fireplace Use							
3. Hours of Opened Windows							
4. Minutes of all Exhaust Fan Use:							
5. Minutes of Clothes Dryer Use (inside home only)							
6. Unusual Events (Place number under appropriate day and indicate below the event and its impact)	1.						

(Example: 1. Party with several guests.)

- END -

DATE FILMED

11 / 06 / 90