Indoor Air Quality & Ventilation Strategies in New Homes in Alaska

Final Report

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September 2002

Contract Details

Start Date: **1/30/2001** ***End Date:*** **9/30/2002**

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Acknowledgements :

ABSN wishes to acknowledge and thank the support of the following individuals and organizations:

Steve Morris, Larry Taylor and Ann Schlappia
Municipality of Anchorage
Health & Humans Services Air Quality Division

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An Investigation of Indoor Air Quality & Ventilation Strategies in New Homes in Alaska

Ginny Moore, Phil Kaluza, Alaska Building Science Network – September 2002

ABSTRACT

Sixty five homes located in Anchorage, Fairbanks, Juneau and Kenai Alaska, and with a range of ventilation systems, were monitored for carbon monoxide, benzene, temperature, relative humidity and particulates over a 48-hour period. Statistical techniques were used to relate air quality characteristics to variables describing architectural, behavioral and environmental characteristic in the homes.

The project's primary objectives were:

1. To determine if there is a significant differences in carbon monoxide, benzene, and relative humidity concentrations in homes with different types of ventilation systems.
2. To determine if different garage/house configurations ("tuck-under", "one wall-attached" or "not attached"), affect carbon monoxide and benzene concentration inside homes with different types of garages
3. To identify architectural, behavioral and environmental factors that might affect air quality, and
4. To determine possible correlation between carbon monoxide and benzene concentrations, so that the simpler, less expensive carbon monoxide measurement might be used as a surrogate for benzene exposure.

Within the limitations of this study, homes equipped with HRVs as a whole-house ventilation strategy had lower concentrations of carbon monoxide, benzene, and relative humidity than either of the other types of ventilation. There was a significant correlation between house and garage concentrations of carbon monoxide and benzene, indicating garages as a strong source for both benzene and CO in the home. Benzene concentrations exceeded the Minimal Risk Level (MRL) in 41% of the homes.

Keywords: indoor air quality, benzene, carbon monoxide, particulates, relative humidity

EXECUTIVE SUMMARY

INTRODUCTION

There has been increased interest in residential indoor air quality issues in recent years. Previous studies have found higher concentrations of some pollutants inside homes than in the surrounding ambient atmosphere. The Alaska Building Energy Efficiency Standard that was adopted in 1992 provides guidance on ventilation methods aimed at reducing humidity and moisture problems in homes. The effectiveness of these methodologies on removing toxic pollutants such as carbon monoxide and benzene is largely unknown.

This study monitored carbon monoxide, benzene, temperature, relative humidity and particulates inside 65 homes in Anchorage, Juneau, Fairbanks, and the Kenai Peninsula that were built since the adoption of the standard. These homes had a range of ventilation systems including intermittent bath/kitchen exhaust only; whole-house exhaust/passive supply; and balanced heat recovery ventilation (HRV). All of the homes were occupied during the study period.

OBJECTIVES

The project's primary objectives were:

1. To determine if there is a significant differences in carbon monoxide, benzene, and relative humidity concentrations in homes with different types of ventilation systems.
2. To determine if different garage/house configurations ("tuck-under", "one wall-attached" or "not attached"), affect carbon monoxide and benzene concentration inside homes with different types of garages
3. To identify architectural, behavioral and environmental factors that might affect air quality, and
4. To determine possible correlation between carbon monoxide and benzene concentrations, so that the simpler, less expensive carbon monoxide measurement might be used as a surrogate for benzene exposure.

METHODOLOGY

Instruments placed in each home monitored CO, benzene, %RH and temperature for a two-day period during the winter of 2002. CO, temperature and %RH were measured continuously with average values stored every two-to -ten minutes. Passive sampling badges incorporating an activated carbon absorption element were used to determine average benzene concentrations.

Parameter Measured	Units of Measure
Carbon Monoxide	Parts per million (ppm)
Benzene	Parts per billion (ppb)
Relative Humidity	Percent (%)
Temperature	Degrees Fahrenheit (°F)

At the time instruments were deployed, field investigators also performed a walkthrough of the building to identify and record building characteristics, ventilation and heating system characteristics, moisture problems, and other possible architectural and environmental factors that might affect pollutant concentrations.

Participants in the study were asked to complete a questionnaire relating to their homes (type, size, cooking fuel, heating system, ventilation system) and activities (times when they typically cook, when the heating is on, whether they smoke etc.) during the course of monitoring. The information obtained from the questionnaires was analyzed to identify activities which may affect pollutant concentration.

RESULTS AND DISCUSSION

Analysis of the monitored data and home surveys provided the following conclusions for each parameter:

Benzene:

1. Benzene readings in the house were reported for 63 homes, of which 26 (41%) had benzene concentrations above the laboratory's minimum detection limit (MDL). Twelve of these homes had readings between 4 ppb and 10 ppb, and 14 homes (22%) had readings greater than 10 ppb, with the highest reading at 50 ppb. The benzene readings for the remaining 37 homes (59%) were reported as being less than the MDL, which varied from 4 ppb-10 ppb, depending upon monitoring period and laboratory used for analysis.
2. The US Government's Minimal Risk Level (MRL) for benzene is 4 ppb for intermediate (14 -364 days) duration exposure. Because this level is below the MDL for the majority of homes, it is impossible to say with certainty what percentage of these homes had concentrations that exceeded the MRL. However, by using similar Alaskan studies and accepted statistical practices, we have estimated that house concentrations in excess of 4 ppb exist in at least 55% of the homes. It is important to note, however, that the MRL does not connote a dangerous level, rather it is a level below which the CDC has confidence that minimal risk exists.
3. Homes without centralized ventilation system had higher concentrations of benzene than homes with central exhaust or HRVs. Average benzene concentrations were highest in houses with tuck-under garages and no centralized ventilation system, while 75% of the homes with HRVs had house benzene concentrations below the minimum detection limit of the passive samplers.
4. There was only a weak correlation between benzene and the number of vehicles in the garage. Garages with older vehicles recorded higher concentrations of benzene. The study was not able to establish a correlation between benzene concentrations and the presence of other small vehicles or fuel in the garage.
5. Homes with tuck-under garages and furnaces within the garage had higher benzene concentrations than any other garage/heating system combination, and they were 43% higher than concentrations in homes with one-wall-attached garages and furnaces.
6. There was a significant difference between garage types in the proportion of benzene from the garage that entered the house. The average house/garage ratio of benzene for tuck under garages was 65% higher than one-wall-attached garages. (Only 2 homes in the sample did not have attached garages and their house benzene concentrations were below minimum detectable limits.)

Carbon Monoxide (CO):

1. No homes had measured indoor carbon monoxide concentrations above the EPA standard of 35 ppm/1 hr or 9 ppm/8 hr. Average 1-hr CO concentration was 3.7 ppm.
2. Although no statistically significant difference in CO peak or mean concentrations was found between different ventilation strategies, homes with HRVs averaged lower concentrations of CO than either of the other types of ventilation
3. CO house peaks appeared to be associated with automobile use; peak house concentrations followed and correlated with garage peaks.
4. Garage CO concentrations were correlated to the number of vehicles in the garage (and thus the amount of vehicular activity). No other architectural, behavioral or environmental factor was as strongly associated with elevated CO.
5. There was a significant correlation between garage and house CO concentrations.
6. There was a good correlation between average garage CO and benzene concentrations, but no apparent correlation between average house CO and benzene concentrations. This may be due in part to other sources of CO within the house, such as cook stoves.

Particulates:

1. The study was not able to establish a correlation between particulate levels and ventilation types.
2. Particulate level peaks appeared to be primarily associated with automobile use; house particulate peaks followed and correlated with garage CO peaks.
3. The study found no correlation between particulate levels and heating system type; nor did it establish a correlation between particulate levels and filter types, air cleaners, vacuum cleaner types, number of pets.
4. There was a positive correlation among all sizes of particulates measured, indicating a consistency in the major source(s) of particulates.

Relative Humidity and Temperature:

1. The average Relative Humidity inside homes was 27%.
2. Homes with HRVs averaged lower relative humidity levels than homes with other types of ventilation. A large proportion of homes with HRVs were in Fairbanks, supplying dry winter air.
3. We found no correlation between relative humidity and the number of occupants, plants, or presence of a humidifier.
4. The walk thru assessment found little or no moisture related problems within the homes. All basements and crawlspaces, with the exception of one where the homeowner had removed the poly ground cover, were found to be as dry as expected during the winter months. Some moisture damage was noted in the crawlspace on several rim joists.

CONCLUSIONS

Within the limitations of this study, homes equipped with HRVs as a whole-house ventilation strategy had lower concentrations of carbon monoxide, benzene, and relative humidity than either of the other types of ventilation. There was a significant correlation between house and garage concentrations of carbon monoxide and benzene, indicating garages as a strong source for both benzene and CO in the home. Benzene concentrations probably exceed the Minimal Risk Level (MRL) in 55% of the homes.

1.0 Introduction

This project was funded by the Cold Climate Housing Research Center in Fairbanks, Alaska and carried out by independent investigators working with Alaska Building Science Network between January 2001 and July 2002. The final report summarizes the work undertaken and the findings of the study.

The project involved the monitoring of carbon monoxide (CO), benzene, relative humidity (%RH), temperature and particulates in 65 houses in Anchorage, Juneau, Fairbanks, and the Kenai Peninsula, with a range of ventilation strategies, all of which were permissible under the Building Energy Efficiency Standard (BEES. Homes were monitored intensely for a 2 day period, air leakage was provided from earlier tests and occupant use by questionnaire. Most monitored homes were constructed after 1994, (i.e. no more than 8 years old at the start of the study). Two 25-year old homes were included for comparison.

Alaska Building Science Network contracted with building scientists in four regions of Alaska to install monitoring equipment and collect data for individual homes.

1.1 Background

There has been increased interest in residential indoor air quality issues in recent years. Previous studies have found higher concentrations of some pollutants inside homes than in the surrounding ambient atmosphere. The Alaska Building Energy Efficiency Standard that was adopted in 1992 provides guidance on ventilation methods aimed at reducing humidity and moisture problems in homes. The effectiveness of these methodologies on removing toxic pollutants such as carbon monoxide and benzene is largely unknown.

In Alaska, homes that have been built since the adoption of BEES have ventilation systems that include:1) intermittent bath/kitchen exhaust only; 2) whole house exhaust/passive supply; 3) heat recovery ventilation (HRV). In this investigation, the impact of each of these types of ventilation systems has been studied.

The project's main objectives were:

1. To compare the impact of different methods of ventilation on carbon monoxide, benzene, and relative humidity concentrations,
2. To compare carbon monoxide and benzene concentration concentrations in garages and living areas of homes with different types of garages ("tuck-under", "one-wall-attached", or "none"),
3. To examine architectural, behavioral and environmental factors that might affect air quality concentrations, and
4. To determine if there is a strong correlation between carbon monoxide and benzene concentrations in the house that the simpler, less expensive carbon monoxide measurement might be used as a surrogate to benzene exposure.

2.0 House Selection and Description

The focus of the study was homes that were built since the adoption of BEES. No effort was made to randomize the selection of homes sampled. Participation was solicited by contacting approximately 400 individual property owners whose homes had been energy rated as part of verification of compliance with BEES.

An objective of the study was to correlate indoor air quality concentrations with the architectural, behavioral, and environmental characteristics of the home environment. A survey was designed to accompany the air quality monitoring, using a set of factors outlined in a previous indoor air quality study developed by the Municipality of Anchorage.[1]

These factors included:

Architectural factors:

- Dwelling type (single family, small multifamily, large multifamily, mobile home)
- Type of Garage (none, one-wall-attached, tuck-under)
- Mechanisms affecting airflow within the home or garage
- Age of the home
- Size of living area (sq.ft.)
- Heating system type (forced air furnace, hot water boiler, direct heat)

Behavioral factors:

- Frequency of automobile use (number of trips taken
- Age of vehicle(s) in garage
- Storage of fuel or volatile chemicals in home or garage
- Cigarette smoking inside home
- Recent interior painting or remodeling
- Use of fireplace, wood stove, during sampling periods
- Use of ventilation fans

Environmental factors:

- Ambient outdoor temperature, wind speed
- Ambient outdoor benzene, carbon monoxide, particulate concentrations

3.0 Methodology Development and Pilot Study

3.1 Methodology Development

The first task of this project involved the investigators familiarizing themselves with the monitoring equipment and software to be used. The second task was testing the protocols developed for deploying and retrieving the monitoring equipment. The final assessment protocols that were developed are included as Appendix 2.

This equipment included; Hobo Temp/RH data loggers, CO data loggers, particulate loggers, and passive VOC badges. Finally, the instruments were tested for accuracy. 20 Temp/RH loggers were deployed together and their reading compared against each other. Two loggers were rejected because their RH readings were reading significantly different than the other 18. The remaining loggers were found to be within a few percent of each other. The CO loggers were calibrated per the manufacturers' procedures using a zero CO gas and a 50 PPM CO gas. The CO loggers were also tested against a 9 ppm CO gas prior to being used in the field. The particulate loggers were new and the calibration certified by the manufacturer.

3.1 Pilot Study

A pilot study was undertaken to refine and standardize the methodology of measuring CO/benzene levels in homes and one-wall-attached garages, as well as to record temperature/relative humidity and particulate levels.

In the pilot study one of the investigators home in Anchorage was monitored for a period of one week. Continuous measurements for carbon monoxide and particulates levels along with temperature and relative humidity were made in the house and in the garage.

Due to cost constraints, the decision was made to utilize the 3M Organic Vapor Monitors for monitoring benzene concentrations in the house and garage. In order to evaluate the accuracy of the passive Organic Vapor Monitors for benzene, the Municipality of Anchorage Air Quality staff offered to do a collocate evaluation using evacuated air sampling canisters. A total of eight air samples were taken over a 48 hour period and 12 Organic Vapor Monitors were deployed.

3.1.1 Problems encountered during the pilot study

No significant problems were encountered.

3.1.2 Summary of findings from pilot study

- The protocols and assessment forms for the deployment and retrieval of the testing equipments were modified slightly to assure good tracking of the equipment with houses.
- The monitoring equipment performed as anticipated without any significant problems

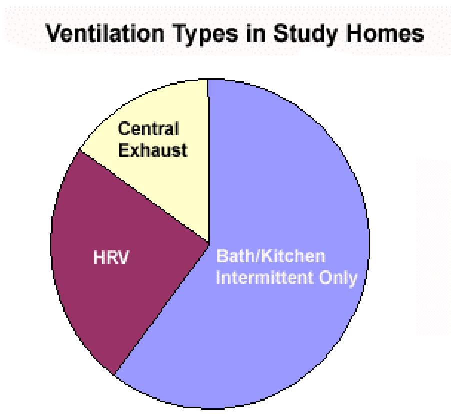
- The results of the validation test indicated the 3M passive VOC badges were reasonably accurate (+/- 2 ppb) as compared to the air sample results. The downside of using the inexpensive Organic Vapor Monitors was the minimum detection limit for a 48 hour monitoring period was approximately 9 ppb. Further information regarding the validation testing is available from Larry Taylor at the Municipality of Anchorage Air Quality Department.

4.0 Building Characteristics and Survey Results

The homes in the study were predominantly constructed after the Alaska Building Energy Efficiency Standard went into effect in 1992. Two older homes were included for comparison.

The types of ventilation systems encountered were unfortunately not evenly distributed. Although we originally intended to monitor similar numbers of different ventilation strategies, this was not possible due to the fact that in Anchorage, where most of the homes were located, the typical ventilation system was only an intermittent bath/kitchen fan system. The different types of ventilation strategy studied were therefore heavily biased towards the overall cheapest type, namely exhaust fans with passive air supply.

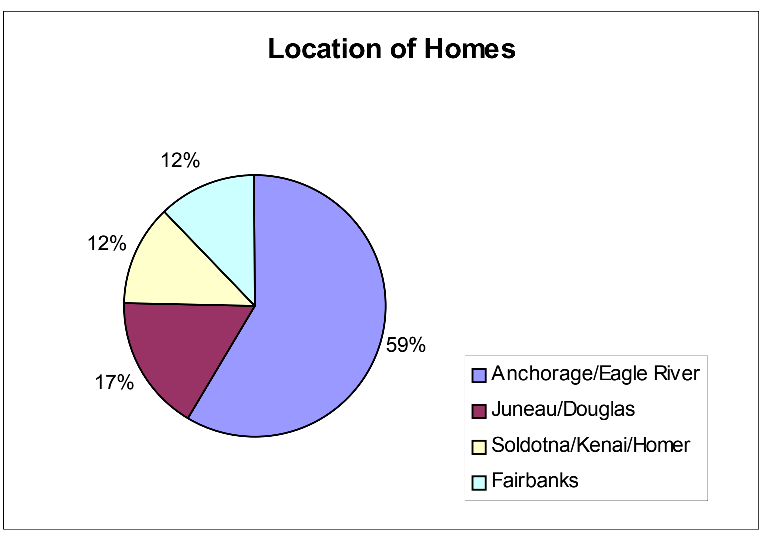
Figure 4.0.1 shows a breakdown of the ventilation types encountered and it is probably a realistic reflection of the variation of ventilation systems in the new housing stock.



Distribution of Ventilation System Types		
Type	Total	% 65
Bath/Kitchen Intermittent Only	39	60%
Central exhaust fans/passive make up air	10	15%
Balanced, heat recovery ventilation (HRV)	16	25%

Figure 4.0.1: Numbers and percentages of ventilation types.

The properties included in the survey were principally detached, single-family homes. They were located in four different localities and climate zones within the state (see Figure 4.0.2).



Distribution of Homes	
Location	# of Homes
Anchorage Area	38
Juneau Area	11
Kenai Area	8
Fairbanks Area	8

Figure 4.0.2 Areas in which the houses were located

Table 4.0.1 summarizes the building characteristics of homes used in the study. Table 4.0.2 summarizes the responses from the initial homeowner surveys. Appendix III, at the end of this report includes a sample of the homeowner survey forms.

Table 4.0.1 - Building Characteristics

House Type	Detached	Duplex/Multifamily					
	59 (91%)	6 (9%)					
Heating System	Gas	Oil	Electric	Propane			
	43 (66%)	20 (31%)	1 (1.5%)	1 (1.5%)			
Heating System Location	Garage	Living	Basement	Crawl	Mechanical Room		
	51 (78%)	5 (8%)	2 (3%)	2 (3%)	5 (8%)		
Garage Types	None	Tuck-under	One-wall-attached				
	2 (3%)	39 (60%)	24 (37%)				
Foundation Types	Heated Crawl	Unheated Crawl	Basement	Pilings	Slab	Split Entry	Walkout
	31 (48%)	3 (4.5%)	7 (11%)	3 (4.5%)	4 (6%)	2 (3%)	15 (24%)

Table 4.0.2 - Homeowner Survey Responses	Number	Percentage
Smokers in the house	7	11%
Smokers who used only one room for smoking	6	86%
Homes with asthma suffers	10	15%
Homes had someone who suffered from some other type of respiratory problem	13	20%
Homes had someone who suffered from some type of allergy	18	28%
Said their problems were worse in winter	13	20%
High Humidity		
Never	31	48%
Seldom	29	45%
Often	2	3%
Low Humidity		
Never	22	34%
Seldom	11	17%
Often	19	29%
Plants		
None	6	9%
Less Than 5	16	25%
5-10:	22	34%
More than 10	20	30%
Humidifier:		
None	45	69%
Portable	19	29%
Whole house:	1	2%
Used the humidifier often	8	12%
Pets:		
Fish Tanks	9	14%
Dogs		
None	27	42%
1	27	42%
2 or more	11	17%
Cats		
None	50	77%
1 or more	15	23%

5. Methodologies For Individual Pollutants

5.1 BENZENE

This aspect of the study was designed to establish current exposure levels to toxic organic compounds, primarily benzene, in indoor air in new homes, for comparison with published risk assessments, guidelines and standards.

5.1.1 Background

Benzene is a colorless, volatile, flammable liquid at room temperature and gives off a vapor that has an aromatic odor. Benzene can be produced commercially from crude oil, natural gas condensates or coal. Benzene is a natural component of petroleum. In gasoline, benzene acts as an octane-enhancer and an anti-knock agent. Benzene is found naturally in the environment in low concentrations. It is a component of crude oil and is formed through incomplete combustion of organic materials.

Benzene enters water and soil through petroleum seepage and weathering of exposed coal-containing strata. The magnitude of vapor emissions from natural sources is not known but, based on concentrations in rural areas, it is believed to be generally low in comparison to man-made sources. Vehicle emissions are the major source of benzene released to the urban environment. In Alaska, the primary source of human exposure to benzene is ambient and indoor air. In the case of indoor air, a major source is cigarette smoke.[2]

Benzene is also used in the manufacture of some detergents, nylon, varnish, lacquer, resins, and oil. However, in 1978 the Consumer Product Safety Commission proposed banning the use of benzene in the manufacture of many household products, and since that time its use has declined.[3]

Current average outdoor ranges for benzene[4] have been found to average:

- 0.3 - 0.8 $\mu g/m^3$ (0.1-0.25 ppb) in rural areas
- 1.8 - 3.6 $\mu g/m^3$ (0.5-1.12 ppb) in urban areas

5.1.2 Health Effects

Benzene is poisonous when ingested and irritating to the mucous membranes. Fatalities from human exposure to high concentrations of benzene have been documented since the early 1900s. Since then, there has been an increasing focus on the impacts of benzene at ever-lower levels of exposure. Human (epidemiological) studies have shown correlations between workplace exposure to benzene and the onset of certain forms of leukemia, and at the same time there has been an increased understanding of the mechanisms by which benzene exerts its toxic effects.[5] Brief exposure (5-10 minutes) to very high concentrations of benzene in air (10,000-20,000 ppm) can result in death. Lower concentrations (700-3,000 ppm) can cause drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness. In most cases, people will stop feeling these effects when they stop being exposed and begin to breathe fresh air, but it is not known how significant chronic low-level exposure to benzene is to human health.[6]

5.1.3 Monitoring

3M passive sampling badges incorporating an activated carbon absorption element were used for short-term sampling of indoor air. These badges operate by diffusion. When the badge is exposed to the atmosphere, air diffuses at a constant rate through a plastic membrane and is adsorbed on a charcoal pad within the badge. The specific contaminant being sampled is then chemically desorbed from the charcoal pad and is analyzed by gas chromatography. Extensive trials were undertaken to demonstrate the reliability of these samplers for this use. (See Section 3.1 Pilot Study.)

Benzene badges were placed in open areas in the house and the garage, and left in place for the duration of the monitoring time (usually 48 hours).

5.1.4 Problems Encountered

Since we weren't relying on instruments and data-loggers, benzene data collection was the most trouble-free of the pollutants we tested. As long as the field investigator remembered to correlate the badge location with the proper badge ID number, and to set the badges membrane-side up, the field work was trouble-free.

5.1.5 Analysis and Results

As noted in Section 3.1 above, a concern with using the passive badges for monitoring benzene is the minimum threshold at which the labs can accurately measure the concentrations of benzene in the air. The canister samplers are much more accurate but are also more expensive and typically are only used for a 24 hour period. Our pilot study indicated that, with a two-day monitoring period, badges could absorb enough benzene to provide readings as low as 9 ppb. Though there are no EPA established safe levels, 4 or 5 ppb for long term benzene exposure is noted in various studies.[7] Our first batch of 10 homes for which we sent in samples showed approximately 25% of the homes had benzene concentrations in excess of the 9 ppb levels. We assumed that there must also be a number of homes between the 5 ppb and the 9 ppb levels that went undetected.

The University of Alaska Environmental and Natural Resources Institute was able to implement the same procedure and bring minimum detection limits (MDL) down to 7 ppb. (During our study we learned of an alternative lab analysis method of benzene badges that can detect lower concentrations of benzene than the standard provided by the 3M lab. The University should also be able to provide this analysis in the future.)

Still, measurements in 17 garages and 35 houses were lower than the minimum detectable level. In order to perform any statistical analysis, some numeric value had to be assigned these locations. Discussions with other researchers indicated that an acceptable protocol in this situation is to assign a value that is halfway between 0 and the MDL. Therefore, for statistical analysis only, all samples that were lab-tested to the 9 ppb MDL were assigned 4.5 ppb, and all samples that were lab-tested to the 7 ppb MDL were assigned 3.5 ppb.

A few homes where benzene badges were in place for longer than 48 hours had overall benzene concentrations high enough that, when time-weighted, a result that was below the MDL was produced.

Table 5.1.1 summarizes the statistics for benzene concentrations when all benzene samples were assigned a numerical value, as described above.

It was not within the scope of this study to apply detailed, sophisticated statistics. We used a basic statistics program to look at correlations between variables, and to develop plots and histograms.

Table 5.1.1 Summary Statistics: Benzene

Benzene	Garage	House
Mean (ppb)*	31.8	8.3
Minimum (ppb)*	3.5	3.5
Maximum (ppb)	200	50.0
Number of homes	45	28

Benzene and Garage Type

We had hoped to have enough variation in garage types to be able to correlate benzene concentrations with the presence or absence of a garage. The previous MOA study found homes with attached garages had significantly higher concentrations of benzene than homes without attached garages. In this study, benzene concentrations in homes with no attached garages was also much lower than for other types of garages, but there were only 2 homes in that category.

This study also compared garages that were attached to one wall of the house (one-wall-attached) with garages that were incorporated within the whole-house footprint (tuck-under). Garage benzene averages were higher for one-wall-attached garages than for tuck-under garages, but house benzene concentrations were higher for houses with tuck-under garages.

Benzene and Heating Systems
The study compared benzene concentrations to different heating system types: boilers, furnaces, and direct heat (Toyo-type). We found no overall correlation between either house or garage benzene concentrations with heating system type. However, homes with boilers had higher garage benzene concentrations, but homes with furnaces had higher average house benzene concentrations.

Benzene and Carbon Monoxide
One goal of the study was to determine if there was enough correlation between benzene and carbon monoxide that the simpler, less expensive carbon monoxide measurement might be used to provide an adequate indication of benzene exposure. Our results indicate that there may be some statistical significance but the correlations were weak. Table 5.2.2 below indicates a significant correlation between house benzene and garage benzene concentrations. A similar correlation was found for house and garage carbon monoxide concentrations (see section 4.3).

Table 5.1.2 Correlations of Benzene and other Variables

Benzene Sample Location	Variable	Correlation	P-Value
House Benzene	Garage Benzene	0.520	0.000
Garage Benzene	Garage CO	0.324	0.039
House Benzene	House CO	0.255	0.071
House Benzene	# Vehicles in Garage	0.247	0.053
Garage Benzene	House CO	0.189	0.277
Garage Benzene	# Vehicles in Garage	0.143	0.348
Garage Benzene	House Particulates (TSP)	0.110	0.468
House Benzene	House Particulates (TSP)	0.042	0.842
House Benzene	Garage CO	0.012	0.933

Boxplots
Boxplots, also called box-and-whisker plots, are particularly useful for showing the distributional characteristics of data. A boxplot consists of a box, whiskers, and outliers. A line is drawn across the box at the median (the middle number in the set). The bottom of the box is at the first quartile and the top is at the third quartile value. So the box represents the middle 50% of the data points. The whiskers are the lines that extend from the top and bottom of the box to values are still meaningful. Outliers are points outside of the lower and upper limits and are plotted with asterisks (*). The width of the box is related to the relative number of data in a category. The adjacent boxplot compares house benzene concentrations by number of vehicles in the garage and indicates that 3 cars in a garage correlated with significantly more benzene in the garage.

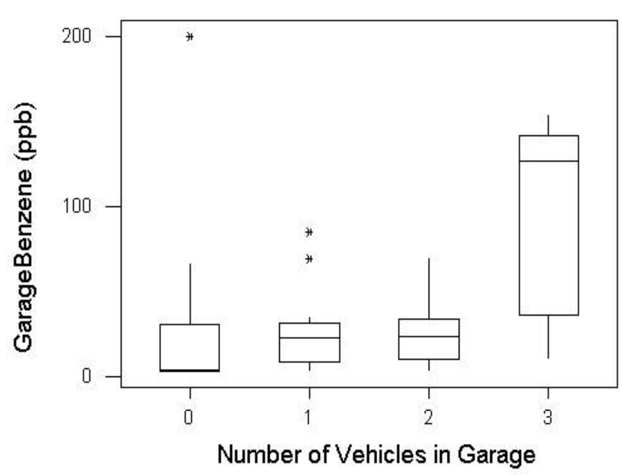


Figure 5.1.1Boxplot, Comparing garage benzene to number of vehicles in garage

Figure 5.1.2 Boxplot Comparing Heating System Type and Benzene in Living Area

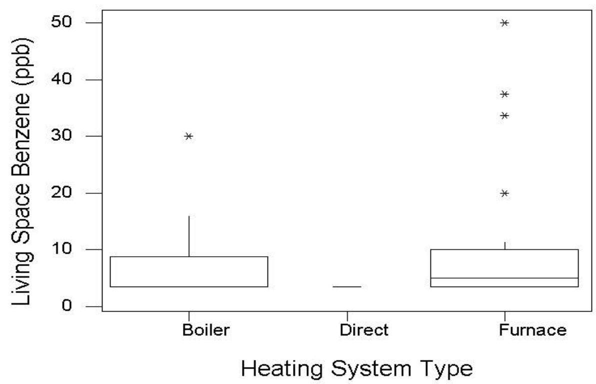


Figure 5.1.2, correlating heating systems to living space benzene, shows the median range for benzene being higher than for other heating system types. It should be noted that there were more furnaces in the total sample.

Figure 5.1.3 Boxplot Comparing Heating Fuel Type and Benzene in Living Area

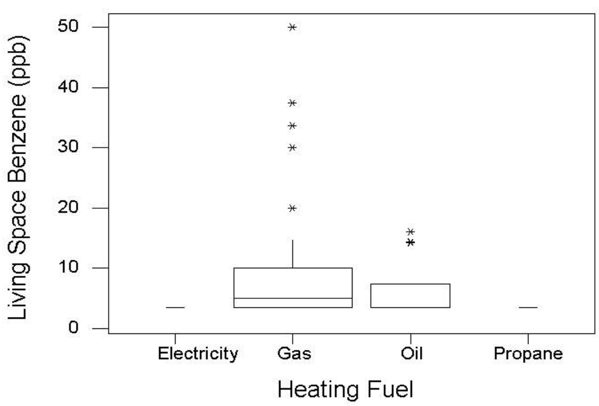


Figure 5.1.3 compares heating fuel type and living area benzene levels and shows that hoes with gas heating systems had higher median and overall benzene levels. There were more gas heating systes in the total sample.

Figure 5.1.4 Boxplot Comparing Ventilation Type and Benzene in Living Area

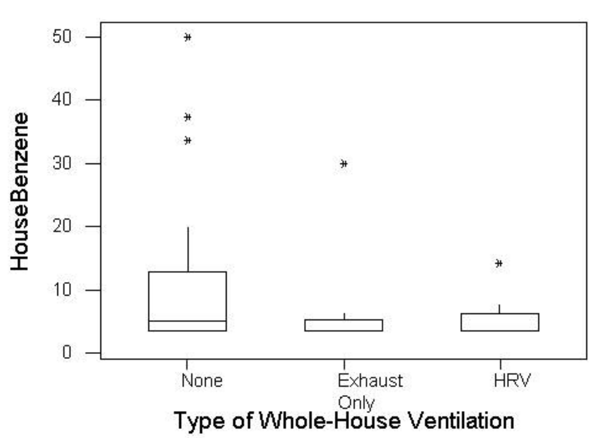


Figure 5.1.4 compares ventilation type and benzene levels in the living area and indicates that homes with ventilation systems had lower levels of benzene in the living area.

Figure 5.1.5 Summary of Descriptive Statistics for House Benzene

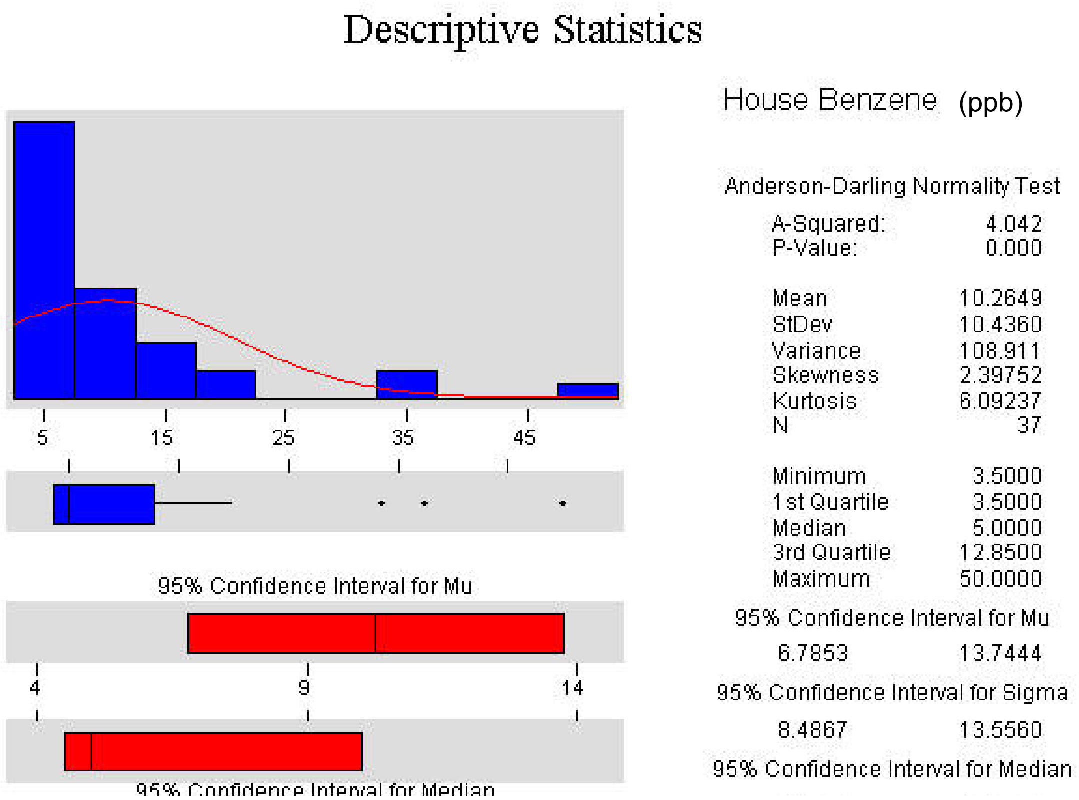
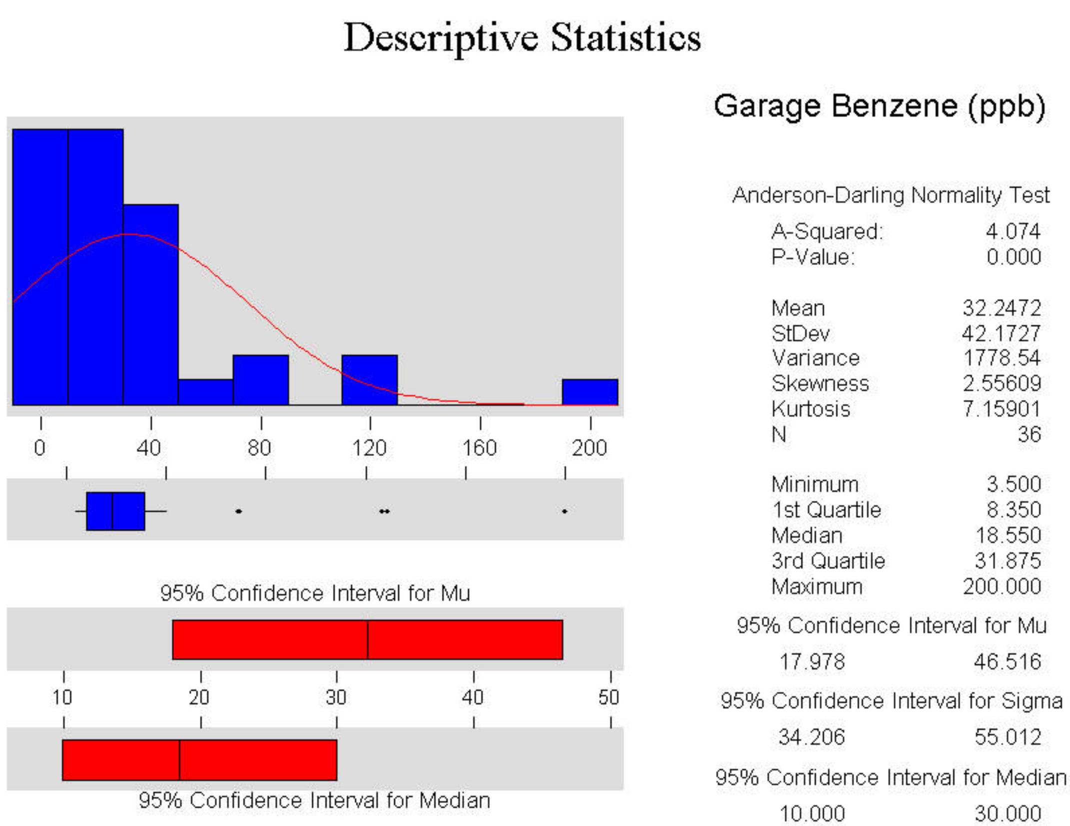


Figure 5.1.6 Summary of Descriptive Statistics for Garage Benzene



5.1.6 Comparisons With Standards and Guidelines

The Occupational Safety and Health Administration (OSHA) has set a permissible short term exposure limit of 1 part of benzene per million parts of air (1 ppm) in the workplace during an 8-hour work day. There are currently no standards for long term exposure, such as living continuously in a home with high concentrations of benzene. However, the Agency for Toxic Substances and Disease Registry has developed Minimal Risk Levels (MRLs) for human exposure to hazardous substances in the environment. An MRL is "an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure"[8]. MRLs are derived from acute (1-14 days), intermediate (14-364 days), and chronic (365 days and longer) exposure durations. ASTDR's MRL for inhaled benzene is 50 ppb at acute exposure range and 4 ppb at intermediate exposure range.

21 homes in the study had 2-day indoor concentrations of benzene measured at 10 ppb or greater.

5.1.7 Conclusions

1. Benzene readings in the house were reported for 63 homes, of which 26 (41%) had benzene concentrations above the laboratory's minimum detection limit (MDL). Twelve of these homes had readings between 4 ppb and 10 ppb, and 14 homes (22%) had readings greater than 10 ppb, with the highest reading at 50 ppb. The benzene readings for the remaining 37 homes (59%) were reported as being less than the MDL, which varied from 4 ppb-10 ppb, depending upon monitoring period and laboratory used for analysis.
2. The U.S. Government's Minimal Risk Level (MRL) for benzene[9] is 4 ppb for intermediate (14 - 364 days) duration exposure. Because this level is below the MDL for the majority of homes, it is impossible to say with certainty what percentage of these homes had concentrations that exceeded the MRL. However, by using similar Alaskan studies[10] and accepted statistical practices, we have estimated that house concentrations in excess of 4 ppb exist in at least 55% of the homes (21 homes). It is important to note, however, that the MRL does not connote a dangerous level, rather it is a level below which the CDC has confidence that minimal risk exists.
3. Homes without centralized ventilation system had higher concentrations of benzene than homes with central exhaust or HRVs. Average benzene concentrations were highest in houses with tuck-under garages and no centralized ventilation system, while 75% of the homes with HRVs had house benzene concentrations below the minimum detection limit of the passive samplers.
4. There was only a weak correlation between benzene and the number of vehicles in the garage. Garages with older vehicles recorded higher concentrations of benzene. The study was not able to establish a correlation between benzene concentrations and the presence of other small vehicles or fuel in the garage.
5. Homes with tuck-under garages and furnaces within the garage had higher benzene concentrations than any other garage/heating system combination; they were 43% higher than concentrations in homes with one-wall-attached garages and furnaces.
6. There was a significant difference between garage types in the proportion of benzene from the garage that entered the house. The average house/garage ratio of benzene for tuck under garages was 65% higher than one-wall-attached garages. (Only 2 homes in the sample did not have attached garages and their house benzene concentrations were below minimum detectable limits.)

5.2 CARBON MONOXIDE

5.2.1 Background

Carbon monoxide (CO) is an odorless, colorless and tasteless gas that can be released into a home by any equipment that burns solid, liquid or gaseous fuels. It is produced as a by-product of the combustion process when any fuel is burned. Some primary sources of CO in the home include automobiles, wood stoves and fireplaces, barbecues, home heating equipment and gas stoves and ovens.

In tests conducted at Brookhaven National Laboratory[11], it was determined that, on average, properly adjusted flame retention oil burners produce about 32 ppm of carbon monoxide. Research conducted by the American Gas Association and the Gas Research Institute[12] indicate that average CO emissions for properly adjusted gas heating equipment is about 47 ppm. These appliances are not considered dangerous as long as the CO being produced is carried through the vent or up the chimney with the flue gases.

Average concentrations in homes without gas stoves vary from 0.5 to 5 parts per million (ppm). Concentrations near properly adjusted gas stoves are often 5 to 15 ppm and those near poorly adjusted stoves may be 30 ppm or higher[13].

Wood stoves and fireplaces produce CO concentrations hundreds of times higher than oil or gas burners. USEPA data[14] indicate that wood stoves and fireplaces can generate CO concentrations of more than 20,000 PPM, or 2% by volume. Therefore, wood stoves and fireplaces may represent a very serious health risk if the combustion exhaust gases are not fully and completely vented from the house.

For comparison purposes, undiluted cigarette smoke contains about 30,000 ppm of CO, undiluted warm car exhaust about 7,000 ppm, and the chimney of a home wood fire about 5,000 ppm. Clean countryside air contains about 0.02 ppm of CO. The smoke from one pack of cigarettes, if distributed uniformly throughout an average sized house, could result in a CO concentration of up to 14 ppm.[15],[16]

5.2.2 Health Effects

An average healthy person at sea level is just barely affected by prolonged exposure to CO concentrations of 9 ppm, but the presence of other pollutants aggravates the situation, and respiratory and cardiac problems pose an increased risk. Chronic exposure to high concentrations of CO (30 to 100 ppm) can lead to long-term deterioration of the cardiovascular system.[17]

CO combines with red blood cells preferentially over oxygen, thus interfering with the blood stream's ability to deliver oxygen to the cells of the body.

Once CO has been introduced, it takes several hours for the blood system to cleanse itself of CO. Headaches are a common early symptom of CO poisoning, but these can be easily mistaken as being due to other causes. Deaths due to CO most commonly occur when one is in an enclosed space for several hours where the concentration is on the order of several hundred ppm.[18]

The health effects can vary from a mild headache to death, depending upon the exposure levels and time, as shown in the table below.[15, 16]

Table 5.2.1 Exposure Time and Symptoms for Various Concentrations of Carbon Monoxide **Source:** Brand, Charles; Carbon Monoxide Questions & Answers. Comfort Line Newsletter; Hart & Iliff Fuel & Energy Systems. Newton, N.J 1999	
Concentration (ppm)	**Exposure Time & Symptoms**
9	Maximum Allowed Outdoor Ambient by EPA
35	Maximum for 8-hour exposure
200	Headache in 2 to 3 hours
400	Life Threatening After 3 hours
800	Headache, Dizziness, nausea in 45 minutes, death in 2 to 3 hours
1600	Headache, Dizziness, nausea in 20 minutes, death in 1 hour
3200	Headache, Dizziness, nausea in 10 minutes, death in 30 minutes
6400	Headache, Dizziness, nausea in 2 minutes, death in 10 to 15 minutes
12800	Death in 1 to 3 minutes

5.2.3 Monitoring

Dräger Pac III portable gas monitors were used for this project. These battery-powered instruments claim to operate for more than 600 hours on fresh alkaline batteries. They require initial calibration with a commercially available calibrating service or a calibration cylinder and test gas ampoules.

To obtain a general idea of ambient air quality, two-minute outside readings were taken at the start and stop of each monitoring session. Then, one monitor was placed in the garage and another in the living area, where they remained for the duration of the monitoring period. (See Protocols in Appendix I).

5.2.4 Problems Encountered

Calibration of the Dräger gas monitors was an on-going concern. Two instruments in the same location did not always provide the same reading. Downloaded data occasionally displayed negative numbers, indicating that “zero” was not always zero parts carbon monoxide.

There was only one instrument available to the project for downloading data from the portable monitors. The CO sensors that were used in locations outside of Anchorage collected data for all homes in that location before being shipped back to Anchorage for downloading. The sensors were battery powered and, twice, batteries ran dead during monitoring.

5.2.5 Analysis and Results

Carbon monoxide data were first summarized to determine how many, if any, homes exceeded the maximum recommended ranges. Table 5.2.2 below summarizes the CO ranges in terms of the 2-day average readings and maximum recordings for both the living area and the garage. Although there were some high maximum recordings, no home exceeded the recommended 1-hour and 8 hour ranges of 35 ppm and 9 ppm, respectively.

Table 5.2.2 Summary statistics of 2-day concentrations of carbon monoxide in garage and living area of homes in Alaska.

	Living Area Location		Garage Location	
	Maximum One-Point Recording (ppm)	2-Day Average (ppm)	Maximum One-Point Recording (ppm)	2-Day Average (ppm)
Average - all homes	5	1	56	4
Minimum –all homes	0	0	0	0
Maximum- all homes	23	5.0	190	18
Number of homes	53	53	56	56

Table 5.2.3 Sample Home Garage & House Data		
Time	Garage	House CO
21:05	0	0
21:15	41	11.5
21:25	38.5	22.5
21:35	30.5	23
21:45	27	22.5
21:55	23	21.5
22:05	19	19.5
22:15	17.5	18.5
22:25	16.5	16.5
22:35	15	15.5
22:45	14	14.5
22:55	13	13
23:05	12	12.5
23:15	11.5	12
23:25	10.5	11
23:35	10	10
23:45	9.5	9.5
23:55	9	8.5
0:05	8.5	8
0:15	8	7.5
0:25	7	7
0:35	7	6.5
0:45	6	6
0:55	6	5.5
1:05	5.5	5
1:15	5	5
1:25	5	5
1:35	4	5
1:45	4	5
1:55	3	5
2:05	3	4
2:15	3	4
2:25	2.5	3.5
2:35	2	3
2:45	2	3
2:55	1	3
3:05	0	3
3:15	0	2.5
3:25	0	1.5
3:35	0	0.5
3:45	0	0

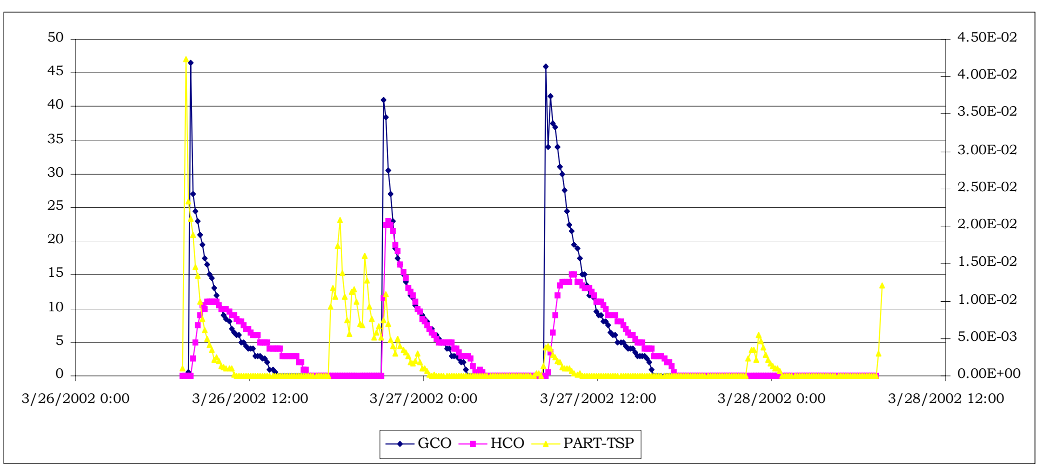
For each house, 10-minute and 1-hour averages for garage and living space CO recordings were gathered into Excel spreadsheets where further interpretation and analysis could be made. Graphs plotted "Garage CO", "House CO" and "Particulate TSP" levels over the course of the monitoring period. Figure 5.2.2 displays a sample graph, and Table 5.2.2 is a selection from that home's data.

The graph in Figure 5.2.1depicts data from the home with the highest single-point maximum living space CO reading during the monitoring period (23 ppm). From the table, we see that the garage CO reading rose from 0 ppm at 21:05 to 41 ppm at 21:15 but was already falling 10 minutes later. The house CO reading followed the same course as garage air infiltrated into the living space. The table also shows that it took almost 17 hours for the house CO to return to 0 ppm after that single incident in the garage. The garage CO returned to 0 ppm about 40 minutes earlier.

The graph also shows that each time there was a major "incident" in the garage the dilution of the air in both the garage and the house followed similar curves. It should be possible to estimate both garage and house ventilation rates by using this information, but our study did not attempt this.

Since house CO levels tracked garage CO levels so well in the majority of homes for which we have data, we can assume that most of the CO levels in the home's living space is very much affected by the CO produced by cars leaving and entering the garage. This was true even though most occupants said they kept the garage/house door closed almost all of the time and they opened the main garage door before starting the car.

Figure 5.2.1. Sample home real time graph of house and garage CO and particulates



Next, correlations, histograms and boxplots were developed to analyze 2-day average CO concentrations. Table 5.2.3 summarizes some of those findings.

Table 5.2.3 Correlations Between CO Measurements and Other Variables

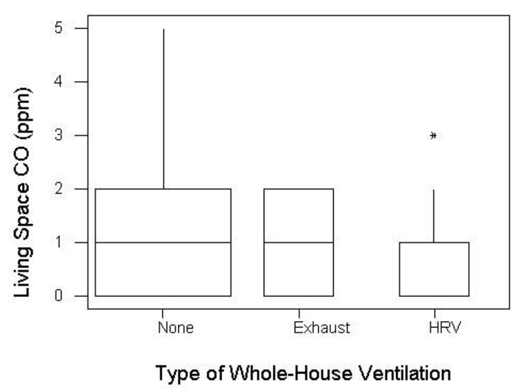
CO Measurement	**Variable**	**Correlation**	**P-value**
Garage CO	# Vehicles in Garage	0.464	0.000 *
Garage CO	House CO	0.369	0.009 *
Garage CO	House Particulates (TSP)	0.264	0.056
Garage CO	Garage Benzene	0.401	0.002 *
House CO	House Particulates (TSP)	0.117	0.420
House CO	House Benzene	0.255	0.071
House CO	# Vehicles in Garage	0.032	0.823
House CO	House ACH_{50}	0.330	0.037 *

We found some correlation between measured house and garage CO concentrations. There was also a correlation between number of cars in the garage and measured garage CO concentrations. Using house airtightness values from blower test results reported on energy ratings, we found some correlation between house CO and airtightness.

The average ranges for house CO did not vary much by heating system type. While the direct heat systems produced no significant CO reading, the average range for boilers was 0.5 ppm and for furnaces about 1 ppm.

No significant correlations were found between house CO and furnace filters, smoking, or any of the other architectural, behavioral and environmental factors we evaluated.

Figure 5.2.2. Boxplot comparing different ventilation systems for carbon monoxide



While there was no statistical correlation between house CO concentrations and ventilation types (Fig.5.2.2), homes with HRVs had lower CO concentrations than homes with other types of ventilation systems. Some of the lack of correlation may be due to malfunctioning instruments in Fairbanks. The box plot shows the variation in CO for each type of ventilation system, with the

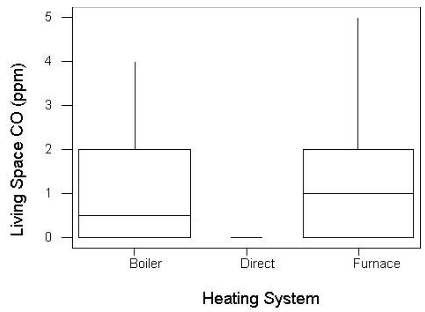


Figure 5.2.2. Boxplot comparing Living Space CO and Heating System Type

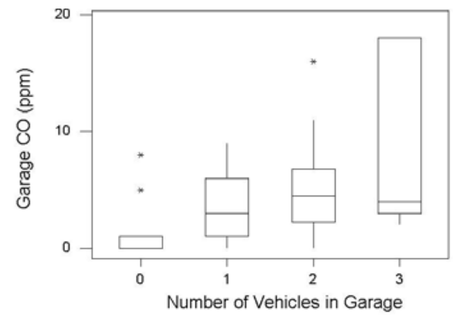


Figure 5.2.3. Boxplot comparing Garage CO and Number of Vehicles

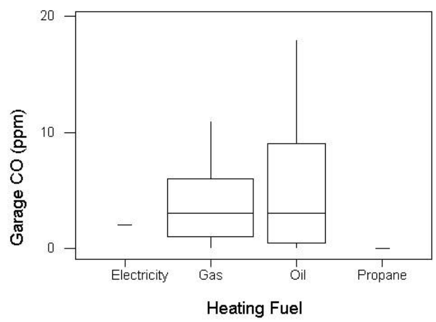


Figure 5.2.4. Boxplot comparing Garage CO and Heating Fuel Type

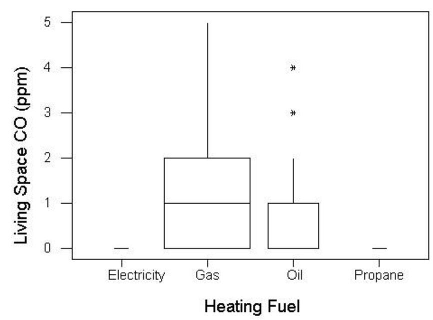


Figure 5.2.5. Boxplot comparing Living Space CO and Heating Fuel Type

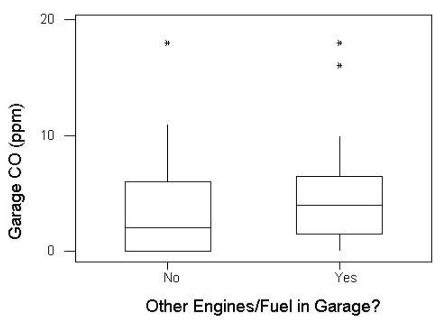


Figure 5.2.6. Boxplot comparing Garage CO and other Engines/Fuel stored in garage.

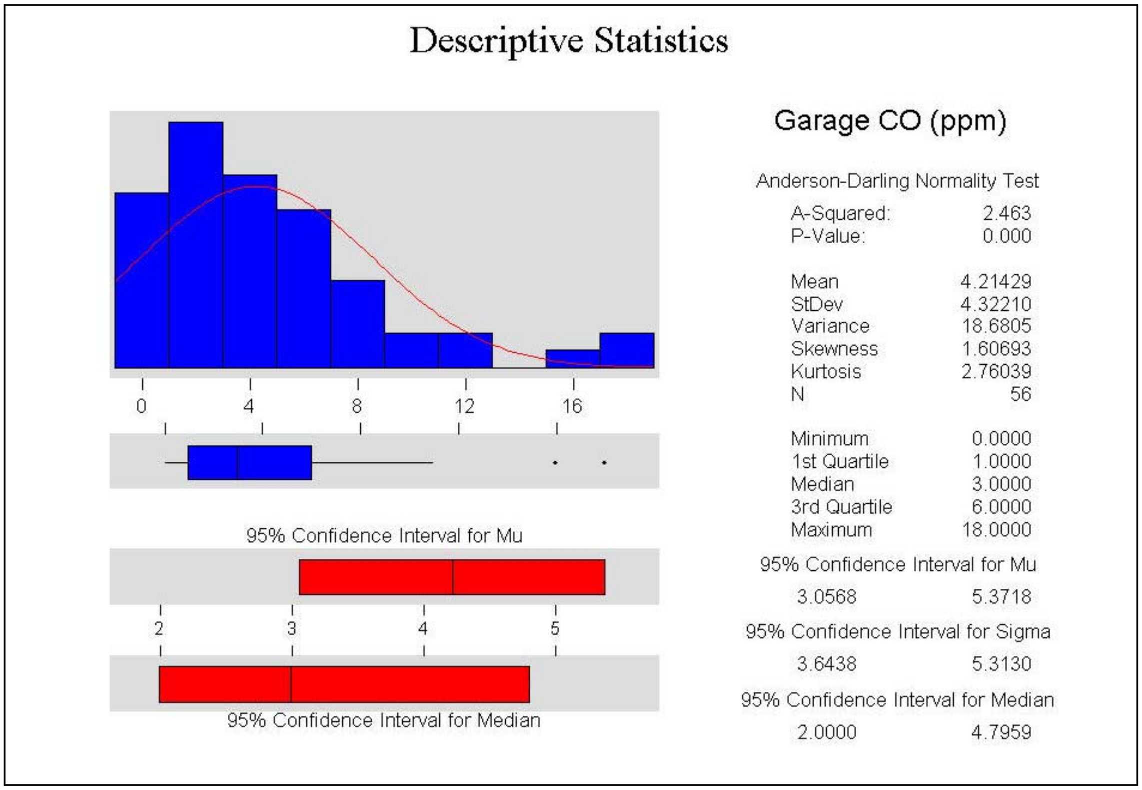
The boxplots on this page compare carbon monoxide levels in the living area or garage with different variables. They illustrate a lack of significant correlation between CO levels and other variables except for number of vehicles in the garage.

5.2.6 Comparisons With Standards and Guidelines

EPA's health-based national air quality standard for maximum outdoor concentrations of CO is 9 parts per million (ppm) measured as an 8-hour average concentration, or 35 ppm measured over any one hour period[19]. No homes had measured indoor carbon monoxide concentrations above the EPA standard of 35 ppm/1 hr or 9 ppm/8 hr. Average 1-hr CO concentration was 3.7 ppm, and maximum 1-hr CO concentration was 22 ppm.

5.2.7 Conclusions

1. No homes had measured indoor carbon monoxide concentrations above the EPA (outdoor) standard of 35 ppm/1 hr or 9 ppm/8 hr. Average 1-hr CO concentration was 3.7 ppm.
2. Homes with HRVs averaged lower concentrations of CO than either of the other types of ventilation No statistically significant difference in CO peak or mean concentrations was found between different ventilation strategies, however.
3. CO house peaks appeared to be associated with automobile use; peak house concentrations followed and correlated with garage peaks.
4. Garage CO concentrations were significantly correlated to the number of vehicles in the garage. No other architectural, behavioral or environmental factor was as strongly associated with elevated CO.
5. There was a significant correlation between garage and house CO concentrations.
6. There was a good correlation between average garage CO and garage benzene concentrations, but no apparent correlation between average house CO and house benzene concentrations. This may be due in part to other sources of CO within the house, such as cook stoves.


Descriptive Statistics
Garage CO (ppm)
0
4
8
12
16
95% Confidence Interval for Mu
2
3
4
5
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 2.463
P-Value: 0.000
Mean 4.21429
StDev 4.32210
Variance 18.6805
Skewness 1.60693
Kurtosis 2.76039
N 56
Minimum 0.0000
1st Quartile 1.0000
Median 3.0000
3rd Quartile 6.0000
Maximum 18.0000
95% Confidence Interval for Mu
3.0568 5.3718
95% Confidence Interval for Sigma
3.6438 5.3130
95% Confidence Interval for Median
2.0000 4.7959

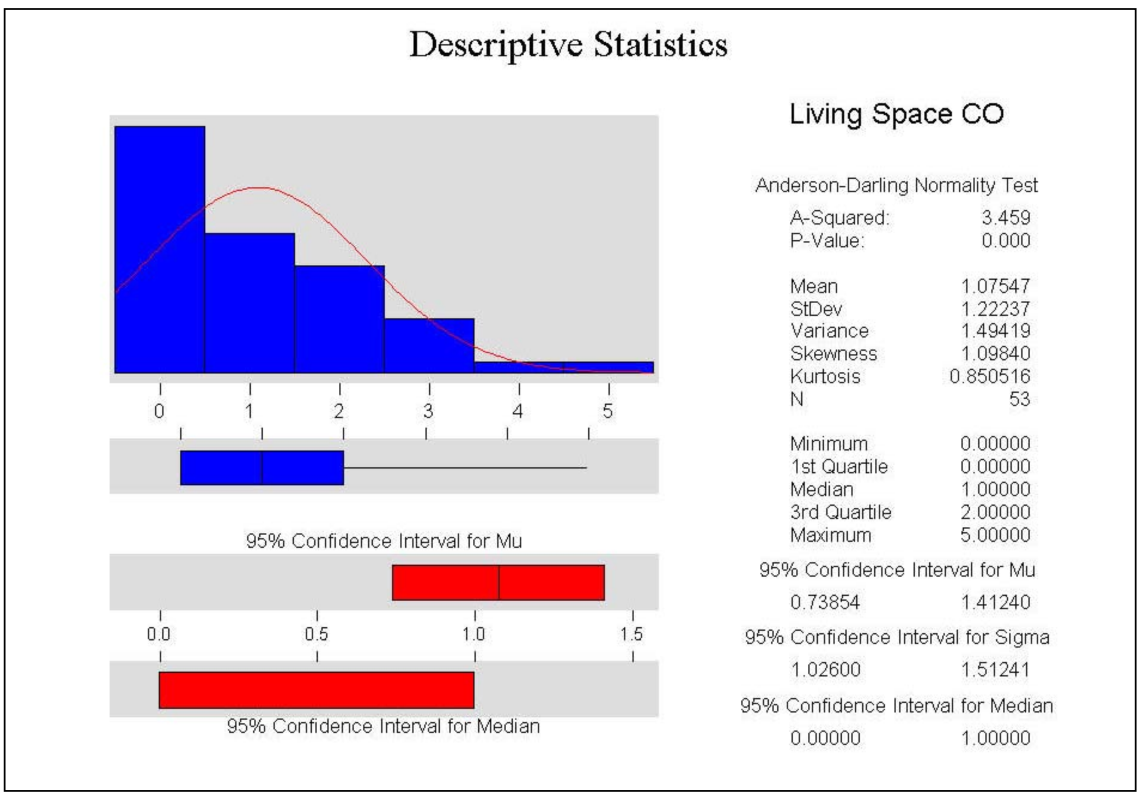

Descriptive Statistics
Living Space CO
0
1
2
3
4
5
95% Confidence Interval for Mu
0.0
0.5
1.0
1.5
95% Confidence Interval for Median
Anderson-Darling Normality Test
A-Squared: 3.459
P-Value: 0.000
Mean 1.07547
StDev 1.22237
Variance 1.49419
Skewness 1.09840
Kurtosis 0.850516
N 53
Minimum 0.00000
1st Quartile 0.00000
Median 1.00000
3rd Quartile 2.00000
Maximum 5.00000
95% Confidence Interval for Mu
0.73854 1.41240
95% Confidence Interval for Sigma
1.02600 1.51241
95% Confidence Interval for Median
0.00000 1.00000

Table 5.2.3 Average Carbon Monoxide and Benzene Concentrations Grouped By House Characteristics and Heating System Type					
Home Characteristics	**Heating System**	**House Benzene Average (ppb)**	**Garage Benzene (ppb)**	**House CO (ppm)**	**Garage CO (ppm)**
Homes w/one-wall-attached garages	Boilers (13)	7.4	40.7	1.3	6.9
	Furnaces (10)	7.2	29.18	1.1	6.1
	Direct (1)	*	*	0	4
	All one-wall-attached (24)	7.3	35.7	1.2	6.5
Homes w/tuck-under garages	Boilers (19)	6.6	32.8	.67	2.6
	Furnaces (19)	11.9	27.4	1.2	3
	Direct (1)	<MDL	<MDL	0	*
	All tuck-under (39)	9.1	29.5	0.9	2.8
Homes no attached garages	Boilers (2)	*	N/A	2.5	N/A
	Furnaces (0)	N/A	N/A	N/A	N/A
	Direct (0)	N/A	N/A	N/A	N/A
	All (2)	*	N/A	2.5	N/A
All Homes (65)	All Heating Systems (65)	8.3	31.8	1.1	4.2

Table 5.2.4 Average Benzene and Carbon Monoxide Ranges by Geographic Location												
Location	Garage Benzene (ppb)			House Benzene (ppb)			Garage CO (ppm)			House CO (ppm)		
	Max	Min	Mean*	Max	Min	Mean*	Max	Min	Mean*	Max	Min	Mean*
Southcentral (n=46)	200	<MDL	30	50	<MDL	9	11	0	3.9	5	0	1.2
Juneau (n=11)	14.2	<MDL	6.2	14.4	<MDL	4.5	5	0	1.5	4	0	0.5
Fairbanks (n=8)	154	41	75.6	16.1	<MDL	8.2	18		9.6	**	**	**
Alaska (n=65)	200	<MDL	31.7	50	<MDL	8.3	18	0	4.2	5	0	1.1

* For statistical evaluation, benzene readings that were below the minimum detectable levels (<MDL) were assigned values of one half the minimum detectable level.

** The CO monitor used to measure Fairbanks "House CO" was not working properly.

NOTE: "N/A" means "Not applicable"
An asterisk (*) signifies data is unavailable

Table 5.2.5 Average Carbon Monoxide and Benzene Concentrations Grouped By House Characteristics and Vent Type					
Home Characteristics	**Vent System**	**House Benzene Average (ppb)**	**Garage Benzene (ppb)**	**House CO (ppm)**	**Garage CO (ppm)**
Homes w/attached garages	No Mech Syst (10)	9.1	25.2	1.1	6.1
	Exhaust Only (4)	10.1	40.5	1.7	3.3
	HRV (10)	4.8	43.2	1.0	8.6
	All attached (23)				
Homes w/tuck-under garages	No Mech Syst (27)	11.0	34.6	1.1	3.4
	Exhaust Only (6)	4.3	12.1	0.8	2.2
	HRV (6)	5.3	23.7	0	0.5
	All tuck-under (39)	9.0	29.5	0.9	2.8
Homes no attached garages	No Mech Syst	4.75	N/A	2.5	N/A
	Exhaust Only	N/A	N/A	N/A	N/A
	HRV	N/A	N/A	N/A	N/A
	All (2)	4.75	N/A	2.5	N/A
All Homes (65)	All Vent Systems (65)	8.3	31.8	1.1	4.2

Table 5.2.6 Average Carbon Monoxide and Benzene Concentrations
Grouped By Location, House Characteristics and Vent Type

Home Characteristics	Whole House Vent System	House Benzene (ppb)	Garage Benzene (ppb)	House CO (ppm)	Garage CO (ppm)
Homes With One-wall-attached Garages	**None(10)**	**9.1**	**25.2**	**1.1**	**6.1**
	Southcentral(9)	8.2	23.2	1.1	4.9
	Juneau (0)	N/A	N/A	N/A	N/A
	Fairbanks (1)	16.1	41.0	*	16
	Exhaust Only (4)	**10.1**	**40.5**	**1.7**	**3.3**
	Southcentral(4)	10.1	40.5	1.7	3.3
	Juneau (0)	N/A	N/A	N/A	N/A
	Fairbanks	N/A	N/A	N/A	N/A
	HRV (10)	**4.8**	**43.2**	**1.0**	**8.6**
	Southcentral(6)	5.0	19.5	1.3	5.5
	Juneau (0)	N/A	N/A	N/A	N/A
	Fairbanks	4.5	78.8	*	11.8
	All attached (23)	**7.3**	**35.7**	**1.2**	**6.5**
	Southcentral(19)	7.5	25.8	1.3	4.6
	Juneau (0)	N/A	N/A	N/A	N/A
	Fairbanks (5)	6.8	71.2	*	*
Homes With Tuck-under Garages	**No None (27)**	**11.0**	**34.6**	**1.1**	**3.4**
	Southcentral (23)	11.4	34.1	1.1	3.5
	Juneau (3)	7.1	7.1	1.3	2.0
	Fairbanks (1)	14.2	129.2	*	4.0
	Exhaust Only (6)	**4.3**	**12.1**	**0.8**	**2.2**
	Southcentral (2)	5.7	23.0	1.5	3.0
	Juneau (4)	3.5	6.7	0.5	1.8
	Fairbanks (0)	N/A	N/A	N/A	N/A
	HRV (6)	**5.3**	**23.7**	**0**	**0.5**
	Southcentral (0)	N/A	N/A	N/A	N/A
	Juneau (4)	3.5	5.1	0	0.7
	Fairbanks (2)	4.5	78.8	*	11.8
	All tuck-under(39)	**9.0**	**29.5**	**0.9**	**2.8**
	Southcentral (25)	10.9	33.2	1.1	3.5
	Juneau (11)	4.5	6.2	0.5	1.5
	Fairbanks(3)	6.8	71.2	*	12.6
Homes with no attached garages	**No None (2)**	**4.75**	**N/A**	**2.5**	**N/A**
	Southcentral (2)	4.75	N/A	2.5	N/A
	Juneau (0)	N/A	N/A	N/A	N/A
	Fairbanks (0)	N/A	N/A	N/A	N/A
	Exhaust Only (0)	N/A	N/A	N/A	N/A
	HRV (0)	N/A	N/A	N/A	N/A
	All (2)	4.75	N/A	2.5	N/A
All Homes (65)	**All Vent Systems** (65)	**8.3**	**31.8**	**1.1**	**4.2**

5.3 PARTICULATE MATTER

5.3.1 Background

Particulate matter is the term given to the tiny particles of solid or semi-solid material found in the atmosphere. Some particles are large or dark enough to be seen as soot or smoke. Others are so small they can be detected only with an electron microscope.

Particulates ranging in size from less than 0.1 micrometer to 50 micrometers are called **Total Suspended Particulates** (TSP). Particles larger than that range tend to settle out of the air.

The size range of concern when human health effects and indoor air quality are considered is from 0.1 to 10 µm in aerodynamic diameter (**PM10)**, particles smaller than this generally being exhaled. Above 15 µm most particles are too large to be inhaled. Virtually all particles between 10 and 15 µm are deposited in the nasopharyngeal region of the respiratory tract; health effects are associated primarily with the deposition of particles in the thoracic regions. Particles have been further divided into a coarse fraction, normally around 2.5 µm and above, and a fine fraction under this size **(PM2.5**). It is this latter fraction that can reach the lung alveoli.[20]

Indoor particles come from both indoor and outdoor sources, but the indoor matter differs in both size and chemical composition from that originating outdoors. Indoors, particles occur primarily in the fine fraction, because indoor sources such as combustion appliances and cigarettes tend to produce fine particles and the building envelope acts as a partial filter [unless using an HRV] to screen out larger particles. Indoor particulate matter contains a much higher fraction of organic matter than that of outdoor air, largely because of household activities such as cooking, cleaning and use of consumer products.

Indoor concentrations of fine particulate matter tend to be higher than those outdoors. Average concentrations of particles under 3.5 µm range between 20 and 30 µg/m^3. Higher concentrations have been noted in "dirty" cities with high outdoor concentrations, and in homes with smokers or wood stoves. Cigarette smoke appears to be the most significant indoor source of particulate matter, and the presence of resident smokers has been shown to raise levels of fine particles in homes by between 12 and 40 µg/m^3 per smoker.[21]

5.3.2 Health Effects

Particles inhaled by humans are segregated by size in the respiratory system. Larger particles deposit in the upper respiratory tract, while smaller inhalable particulates travel deeper into the lungs and are retained for longer periods of time. This is why PM2.5 is of primary concern to health agencies today. Not only does it penetrate deeper and remain longer in the lungs than larger particles, but PM2.5 also contains large quantities of organic materials that may have significant long-term health effects. To date, more research has been completed on the effects of PM10 exposure, but a number of current studies are looking at the effects of PM2.5.

Estimated Health Effects For Particulate PM10 Exposure[22]

Effects Exposure – 24 Hour Concentration

	Effects Possible	**Effects Likely**
Reduced lung function in children	140 µg/m^3	350 µg/m^3
Aggravation of bronchitis Increased mortality	350 µg/m^3	600 µg/m^3

Carbon particles are the most common carriers for gaseous and semi-gaseous pollutants. These pollutants are carried by the fine particulates deep into the lungs where sensitive lung tissues may be exposed to their chemical actions. Benzo-a-pyrene, a known carcinogen, is an example of this type of gaseous or semi-gaseous pollutant.

5.3.3 Monitoring

We used an AEROCET 531 RS-232 particulate data-logger. By means of a laser-diode-based optical sensor, the instrument uses light scatter technology to detect, size, and count particles of sizes 0.5 µm to 10 µm. This detected information can be displayed as particles per size range or may be converted into particle mass using mass-density conversion factors, depending on how the instrument is configured. We chose to configure the instrument to store the data as mass-density (µg/m3) rather than particle size, because that is the most-often used in environmental science reporting. The data was retrieved as mass concentrations PM 1, 2.5, 7, 10 and TSP, measured in µg/m^3. PM 2.5 represents the mass of particles 2.5 microns and smaller, PM7 indicates mass of particles 7 microns and smaller.

To obtain a general idea of ambient air quality, two-minute outside readings were taken at the start and stop of each monitoring session. Then the AEROCET was set up in a prominent area within the house of the building. Because these instruments draw in air, they do make a humming noise somewhat akin to the sound of a fish tank pump. We were able to mitigate the noise a bit by placing them inside padded boxes. Most homeowners were not bothered by the noise.

5.3.4 Problems Encountered

This instrument operates on AC current, with a several-hour battery backup. Unfortunately, it is not possible to tell whether it is operating on AC or DC power, and several times it was plugged into an outlet that later turned out to be switched, and was either switched off at the time or later, by the homeowner. Consequently, we lost a good portion of data for 4 homes.

This instrument was best equipped to provide real-time monitoring data and size-specific particle counting necessary for understanding pulmonary deposition and lung burdens. The mathematical conversion of data probably gave a less accurate indication of actual mass-density than an instrument that is designed to weigh particles.

5.3.5 Analysis and Results

In general, measured particulate levels were not very high in these homes. Table 5.3.1 provides a summary of the two-day averages and maximum concentrations for total suspended particulates (TSP).

Table 5.3.1 Summary statistics: 2-day-average and 2-day-maximum concentrations of TSP concentrations in living areas of homes in Alaska.

For 62 homes	2-Day Averages (µg/m^3)	2-Day Maximums (µg/m^3)
Mean	0.006	0.22
Median	0.005	.084
Minimum	0.0003	.012
Maximum	0.03	2.80

Next, various statistical measures were used to evaluate any possible correlations between particulate levels and other architectural, behavioral and environmental factors. There was no established correlation between particulate levels and ventilation types or heating system types.

Table 5.3.2 Correlation of house particulate levels with other variables.

House Particulates (TSP)	Variable	Correlation	P-value
TSP	Garage CO	0.264	0.056
TSP	# Vehicles in Garage	0.211	0.109
TSP	House CO	0.117	0.420
TSP	Garage Benzene	0.110	0.468
TSP	House Benzene	0.042	0.842

For each home timeline graphs were created, overlaying the readings for particulates (as total suspended particulates – TSP) on the CO graphs, as illustrated in Figure 5.3.1. Although there were many possibilities for rises in TSP, there was often a peak that corresponded to the garage CO peaks. Often the TSP rise began before the garage CO and peaked just after, indicating it was probably related to the rush of activity before leaving.

There were positive correlations between quantities of particulates of sizes PM2.5, PM7, PM10 and TSP. See Table 5.3.1 below. This implies that there was a similar amount of each size particulate and overall particulates in all homes) suggesting that there was a consistency in particulate sources.

Table 5.3.1 Correlations (Pearson)			
	PART-10_	PART-2_5	PART-7_0
PART-2_5	0.857 0.000		
PART-7_0	0.996 0.000	0.891 0.000	
PART-TSP	0.994 0.000	0.821 0.000	0.983 0.000

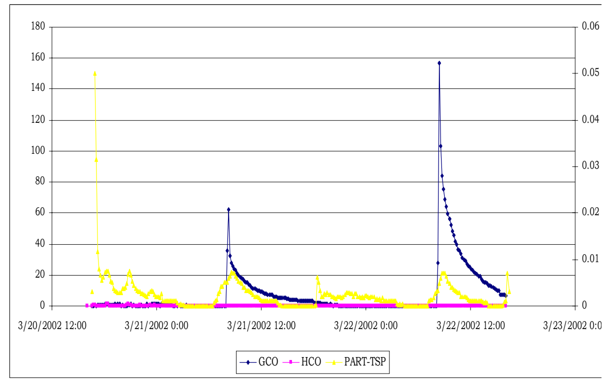


Figure 5.3.1. Timeline measuring House CO (ppm), Garage CO (ppm) and Total Suspended Particulates ( ).

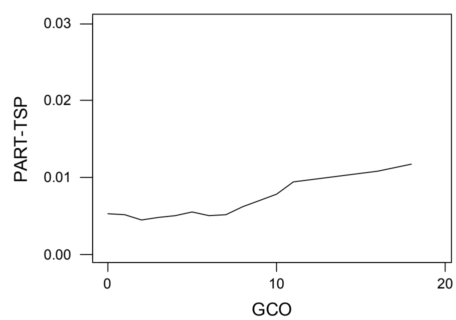


Figure 5.3.2. Relationship of Garage CO (ppm) to Total Suspended Particulates

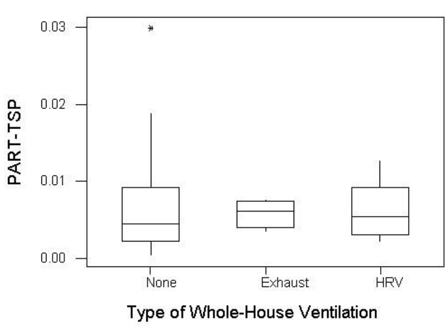


Figure 5.3.3 Boxplot comparing ventilation types to Total Suspended Particulates (ppm) shows little difference in particulate quantities between ventilation types.

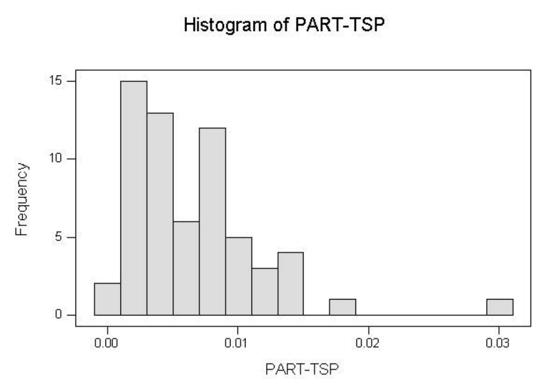


Figure 5.3.4. Histogram of Total Suspended Particulates (ppm) shows that in most homes TSP was below the EPA threshold.

5.3.6 Comparisons With Standards and Guidelines

A review of the data collected for each home indicates that particulate levels in all of the homes monitored were lower than established guidelines. Homes were monitored over a 48 hour span, and total particulate levels did not reach the action levels of EPA's guidelines of 40 micrograms/m^3 averaged over 24 hours.

5.3.7 Conclusions

1. Measured particulate levels in the houses in this study were not found to be of significant quantities to indicate any health concerns. There could be any number of reasons for this, including the general cleanliness of the houses, the time or duration of the study, or the location of the measuring instrument.
2. The study was not able to establish any correlation between particulate levels and ventilation types.
3. Particulate level peaks appeared to be primarily associated with activity in the house related to automobile use; house particulate peaks followed and correlated with garage CO peaks.
4. The study found no correlation between particulate levels and heating system type; nor did it establish a correlation between particulate levels and filter types, air cleaners, vacuum cleaner types, number of pets.
5. There was a positive correlation among all sizes of particulates measured, indicating that the major sources of particulates may have been consistent among all homes.

5.4 TEMPERATURE/RELATIVE HUMIDITY

5.4.1 Background

Molds and mildew are fungi that grow on the surfaces of objects, within pores, and in deteriorated materials. They can cause discoloration and odor problems, destroy building materials, and lead to allergic reactions in susceptible individuals, as well as other health problems.

The following conditions are necessary for mold growth to occur on surfaces:

- temperature range above 40°F and below 100°F
- mold spores
- nutrient base (most surfaces contain nutrients)
- moisture

Human comfort constraints limit the use of temperature as a control of mold growth. Spores are almost always present in outdoor and indoor air, and almost all commonly used construction materials and furnishings can provide nutrients to support mold growth. Dirt on surfaces provides additional nutrients. Moisture control is thus an important strategy for reducing mold growth.

5.4.2 Health Effects

The graph below represents the ranges of relative humidity under which various health problems thrive and highlights an optimum range between 35-55% RH.

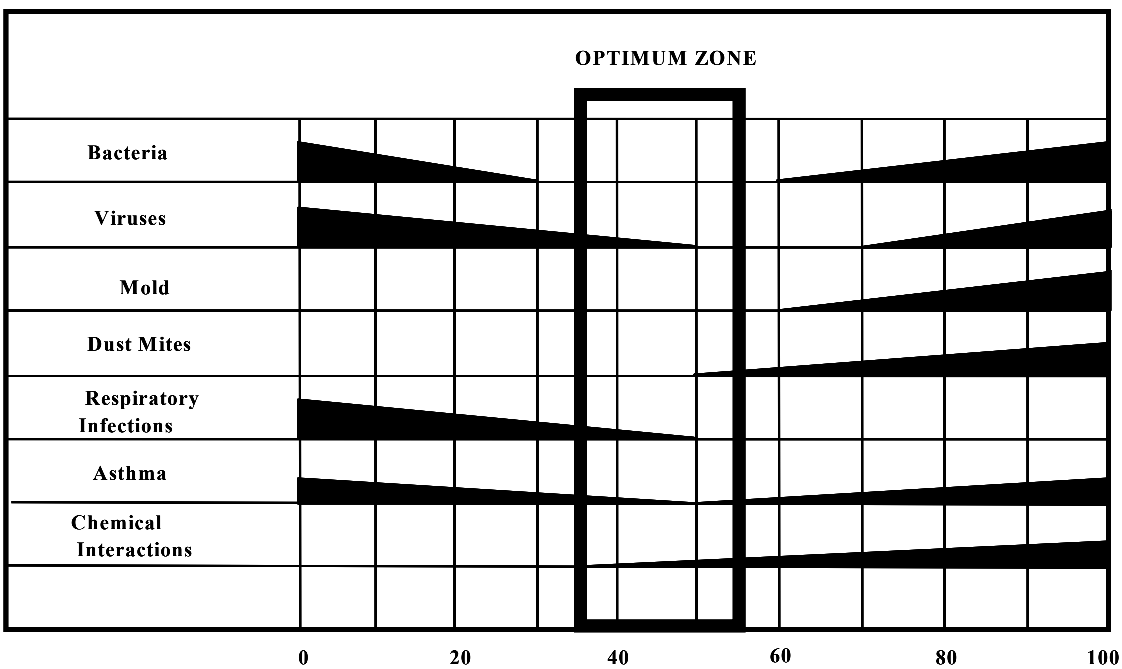


Figure 5.4.1. Relative Humidity Reference Guide **Source: Canadian Homebuilders' Association Builders' Manual, 1989**

5.4.3 Monitoring

Small, battery-powered HOBO® data loggers manufactured by Onset Computer Corporation were placed in the living area and the crawlspace/basement. They continually logged relative humidity and temperature detected by internal sensors.

The HOBO RH and Temperature sensors have an accuracy of +/- 5% RH and +/- X% °F. The instrument is set to measure at 10 second intervals and to average these readings every 6 minutes, giving 10 measurements per hour of each of the variables. The instruments were left running and collected two to three days later to download the data into spreadsheets for analysis.

5.4.4 Problems Encountered

There were some problems with the software used to download data and activate and deactivate the data-loggers. Occasionally data-loggers stopped recording only a short time after being activated. After we became aware of this problem we took extra precautions to activate the instruments far enough in advance to be aware of any problems, and occasionally we used a second data-logger as backup. Several software "patches" that had been developed by the provider were applied during the course of collection, with inconsistent results.

5.4.5 Analysis and Results

The average relative humidity in the living area of all homes in the study was about 27%, ranging from a minimum of 8.3% to a maximum of 48%. As would be expected, homes in Fairbanks, a semi-arid area, had lower RH than homes in the rest of the mostly coastal areas of the state, and Juneau had slightly higher RH than other areas. See Figure 5.4.2. Although there was no strong correlation with ventilation types, homes with HRVs had the lowest average relative humidity. This is likely due to the fact that Fairbanks had a number of HRVs drawing in very dry air.

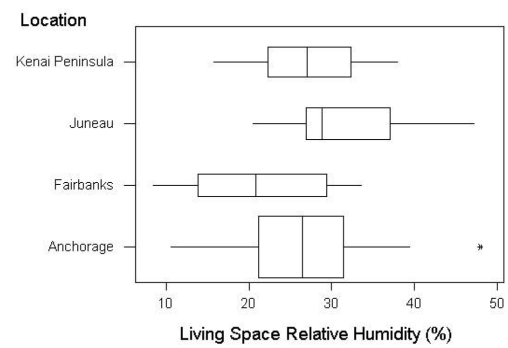


Figure 5.4.2. Indoor Relative Humidity for Locations

Boxplots 5.4.4 and 5.4.5 on the following page show the relationship of relative humidity to number of occupants and to household plants. Relative humidity did not appear to be significantly affected by any one factor, and other than the extreme outliers shown as asterisks in the boxplots, it was relatively consistent among all homes.

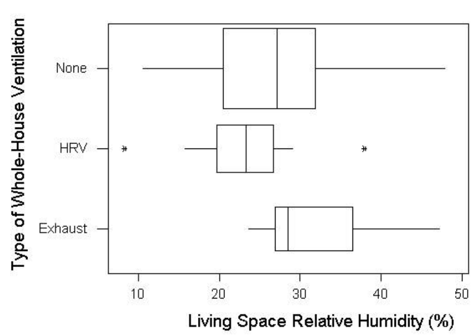


Figure 5.4.3. Indoor Relative Humidity and Ventilation Type

Actual relative humidity levels did not correlate with occupants' perceptions of dryness but most occupants agreed that their homes were more often dry than humid. A number of homes had humidifiers, either portable or whole-house types, but many occupants said they did not use the humidifiers. House relative humidity was about the same with or without a portable humidifier, but relative humidity was best with the single whole-house humidifier.

Table 5.4.1 Summary of Temperature and Relative Humidity Data				
	Number	Mean	Minimum	Maximum
House Relative Humidity	57	26.99 %	8.3%	48%
House Temperature	57	68.7°F	61.6°F	78.8°F
Crawlspace Relative Humidity	31	35.3%	15.9%	83.1%
Crawlspace Temperature	31	57.6°F	38.1°F	75.2°F

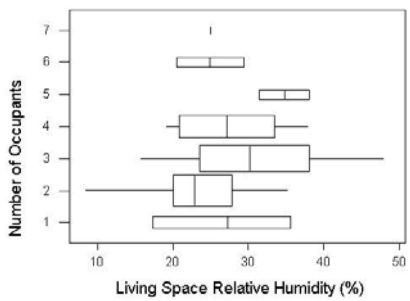


Figure 5.4.4. Humidity and Occuants

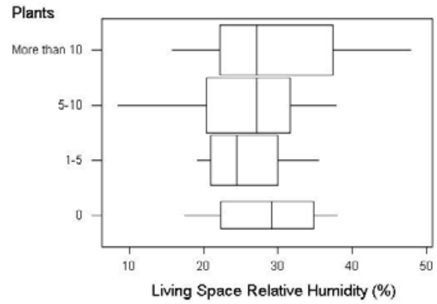


Figure 5.4.5. Humidity and Plants

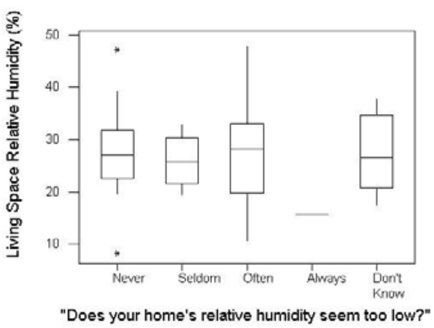


Figure 5.4.6. Humidity and Perception of Low RH

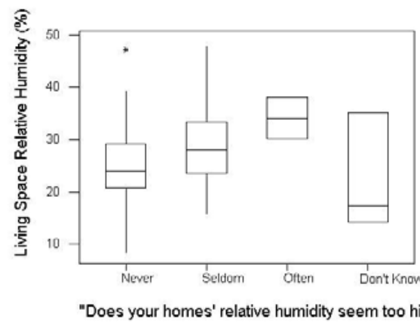


Figure 5.4.7. Humidity and Perception of High RH

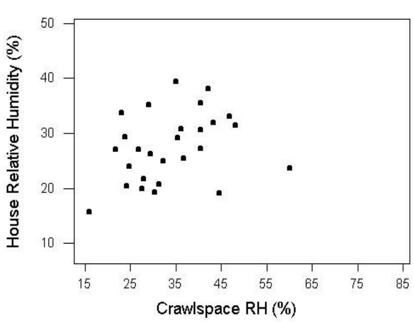


Figure 5.4.8. Scatter plot comparing house RH and crawl RH shows their correlation.

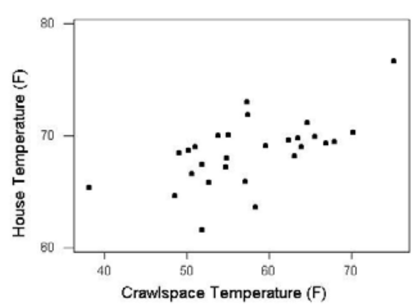


Figure 5.4.9. Scatter plot comparing house temperature and crawl temperature shows their correlation.

5.4.6 Comparisons With Standards and Guidelines

Almost every home studied had house relative humidity lower than the universally recommended 30-50% range. While indoor moisture may not cause problems, this range indicates the possibility of more respiratory illnesses and viruses.

In all but 2 homes, crawlspace RH did not reach the 60% range preferred by molds, but it was higher than house RH, and in combination with relatively high temperatures, could create moisture problems in the crawlspace.

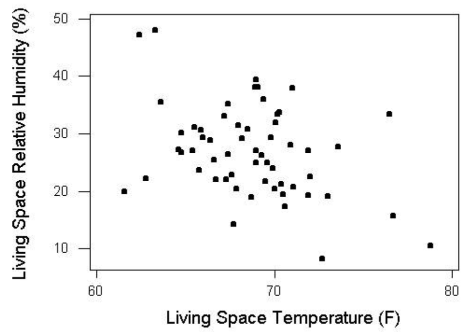


Figure 5.4.6. Scatter plot of living space relative humidity and temperature shows for the majority of homes relative humidity was below the recommended 30-50% range.

5.4.7 Conclusions

1. The average Relative Humidity in the house of all homes was 27%. Indoor moisture generally will not cause problems but this range is conducive to more respiratory illnesses.
2. Homes with HRVs averaged lower relative humidity levels than homes with other types of ventilation.
3. We were not able to correlate relative humidity to number of occupants, plants, or use of humidifier.
4. The walk-thru assessment found little or no moisture related problems within the homes. All basements and crawlspaces, with the exception of one where the homeowner had removed the poly ground cover, were found to be as dry as expected during the winter months. Some moisture damage was noted in the crawlspace on several rim joists. In one case, this correlated with high crawlspace relative humidity (60%), and a crawlspace temperature of 53 °F, and in the other crawlspace relative humidity was only 32%, while the crawlspace temperature was only 62°F.

6.0 House/Garage Connection

Numerous studies[23],[24] have indicated that cars being started in attached garages are the predominate source of benzene and CO in homes in Alaska. The amount of CO or benzene accumulating in the garage air from car starts will depend upon the number of car starts, age of the car, garage temperature, length of time the car idles in the garage, and the amount of time a garage door is left open after the car has left the garage. Other potential sources of benzene include non-airtight gas cans, vented gas tanks found on lawn mowers, snowblowers, and other small gasoline engines. Gasoline spills and leaks in fuel lines can create high levels of benzene within the house. Cigarette smoking is a source for benzene within the living space. CO is generated primarily from cold car starts within the garage. Other sources within the garage may include backdrafting of combustion appliances and starting and/or operating small engines. Living space sources include gas cook stoves, smoking, woodstoves and fireplaces,

The amount of benzene, CO, and other pollutants from the garage air that actually make it into the house depends on several variables:

Holes or leaks between the house and garage.
These leaks at the interface between the house and garage are generally made up of small cracks along the floor perimeter, electrical outlets, garage door mounting brackets, forced-air furnace

platforms, the man-door between house and garage, and duct leakage within the garage. Reducing the amount of leakage between the house and garage can reduce the flow of pollutants from the garage. Unless those pollutants generated in the garage are being removed via some other method, however, whenever the house is depressurized relative to the garage, pollutants will flow into the house.

Pressure difference between the garage and house:

- The "stack effect" generates a continuous small negative pressure on the lower portion of a home, and a positive pressure on the upper portions of the building relative to the outside. This effectively pulls air into the house, from outside and from the garage, at the lower level, and pushes it out of the building at the upper wall and ceiling areas. The strength of the stack-induced pressure is determined by the height of the building, the temperature difference between inside and outside, and the distribution of leaks in the home. Because these pressures are very small, wind, exhaust and furnace fans are capable of easily overpowering the stack effect and may significantly increase or reverse this pressure. A tuck-under garage, because of the increase in overall above ground building height will typically generate a slightly higher stack pressure and has more potential leakage paths than an attached garage.

- A tuck-under garage full of CO may be analogous to a bucket of water with a hole on the bottom of it. It doesn't matter how small the hole is, all the water will eventually leak out on the floor- it is just a question of how quickly. The only way to reduce the total amount of water that lands on the floor is to scoop some water from the bucket before it gets the chance to leak out. Conceivably, if one were able to make the hole small enough natural evaporation may remove it from the floor as quickly as it is able to leak out, so there would be very little if any accumulation on the floor. This may be true of the levels of CO in the garage as well. If we ventilate the garage, we can lessen the amount of CO that enters the house. If we air-seal the garage/house interface we may also slow the flow into the house sufficiently so that house ventilation can dilute it to a safer level.

  Exhaust only ventilation systems, dryers, range hoods, and fireplaces in a home will depressurize the home, potentially increasing the amount of air flow from the garage. The amount of increased ventilation induced by the exhaust fan and the percentage of makeup air that enters through the garage will affect whether the exhaust fan is increasing or decreasing the level of garage contaminates within the house.

- Furnaces and ductwork located within the garage may provide a very significant path for pollutants to enter the home. Duct leaks on the return side of the furnace fan are common on the return plenum and the actual furnace. These leaks provide an easy path for garage air to enter the home. Unbalanced supply and return air create pressure differences within the home. If areas such as crawlspaces or bedrooms that are adjacent to or above a garage become slightly negative, an increase in garage air leakage is possible. This was observed in a bedroom above a garage that had a large return relative to the supply. That bedroom experienced the highest CO peaks in the home.

Pressure testing:
The movement of air between the garage and house is a function of the leakiness of the house/garage interface and the pressure across the interface. Duct leakage within the garage could significantly increase the rate of transfer between the house and garage. In an attempt to quantify the effect of the furnace fan on the pressure across the interface, a simple pressure diagnostics test was performed on those houses with furnaces in the garage. Garage pressure with reference to (WRT) the house was

taken with the furnace fan off (stack effect only) and again, with the furnace fan-only on (stack and fan induced)

The average stack effect with no furnace fan running was 0.6 Pa.
The average stack effect + furnace fan = -1.0 Pa, which meant the garage was depressurized with regard to the house when the furnace fan was running.

Solution:

Reducing or eliminating the positive pressures generated between the garage and house is essential to minimize the flow of garage air into the home. One simple solution is to install an exhaust fan in the garage to maintain a slight negative pressure relative to the home. In this situation air will flow from the house into the garage and then be exhausted by the fan. In order to create this slightly negative pressure with a small exhaust fan, the garage must be substantially air tight and free of naturally aspirating combustion appliances. Garages with combustion air openings would require a much larger exhaust fan and would risk backdrafting the combustion appliance that required the opening. In addition, the energy penalty to heat the garage would be significant.

Canadian research has found running an exhaust fan after each car start for 30 minutes significantly reduced the level of CO in the garage, and subsequently the amount that entered a home. (It should be noted that the Canadian garages were very leaky relative to our current building standards, contain no heating appliances, and are generally not heated.) Until furnaces, plenums, filter boxes, and ducting can be constructed truly airtight they should not be located within the garage.

7.0 Conclusions

Within the limitations of this study, homes equipped with HRVs as a whole-house ventilation strategy had lower levels of carbon monoxide, benzene, and relative humidity than either of the other types of ventilation. There was a significant correlation between house and garage levels of carbon monoxide and benzene, indicating garages as a strong source for both benzene and CO in the home. Benzene levels probably exceeded the Minimal Risk Level (MRL) in 55% of the homes.

8.0 References

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Additional Resources

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Wallace, Lance; *"Environmental Exposure to Benzene: An Update";* Environmental Health Perspectives, Volume 104, Supplement 6, December 1996; U.S. Environmental Protection Agency,

Reston, Virginia Young, A. et. al. *"Carbon Monoxide Concentrations and Ventilation Strategies in Dwellings"*, Bartlett School of Graduate Studies, London, 1998

Internet Resources

American Lung Association: http://www.lungusa.org/
Benzene Info Center: http://www.benzeneinfocenter.com/
Centers For Disease Control and Prevention: http://www.cdc.gov
Indoor Air Quality Association, Inc.: http://www.iaqa.org/guidelines.htm
Health Canada: Exposure Guidelines on Indoor Air Quality: http://www.hc-sc.gc.ca
U. S. Environmental Protection Agency: http://www.epa.gov/oar/aqtrnd97/brochure/pm10.html
National Environmental Technology Centre, UK Department of the Envronment, Transport and the Regions: http://www.aeat.com/netcen/airqual/dailystats/standards.html
National Environmental Technology Centre, UK Department of the Environment: http://www.aeat.com.netcen/airqual
Occupational Safety and Health Administration, US Dep. of Labor: http://www.osha-slc.gov

Appendix I. Assessment protocols used in VIAQ Study

General requirements:

1. Prior to visiting a home, the assessor will review the AkWarm file and familiarize themselves on the insulation levels, air tightness, ventilation and heating systems, etc. of the home.
2. The CO data loggers will be calibrated weekly per manufacturers' instructions. Particle counters will be calibrated weekly using the zeroing filter.
3. All passive samplers will be properly labeled at the time they are installed. All handling and shipping per manufacturer/lab instructions.
4. Location of the samplers: Location must be relatively secure from small children to avoid damage to the equipment. All electrical plug-ins will be located where there is little likelihood of an occupant unplugging them.
   a. Particle counter: Main living area, should be at the sitting breathing level if possible. (4-5')
   b. CO data loggers – Main living area and garage, 4-6' off the floor, and not exposed to elevated temperatures, air flow, etc.
   c. Benzene samplers: Main living area and garage, and 4-6' high off the floor in the garage, not exposed to elevated temperatures, air flow, etc.
   d. Indoor temp/RH data loggers will be installed in the main living area and in the crawlspace or basement if applicable. (The crawlspace Temp/RH data logger could be secured to a string and hung down from the crawlspace hatch such that one would not need to actually go back down into the crawlspace.)

Initial walk-thru visit:

1. Prior to entering a home, assessor(s) will take a CO and particle sample of the outdoor air and record those results.
2. During the initial interview the survey forms will be completed. If two assessors are present, the other assessor would begin installing the monitoring equipment. When the initial interview is completed, the assessors should be aware of any potential problems identified by the homeowner.
3. The walk-thru assessment form will be completed. Assessor is encouraged to take lots of digital photos of IAQ related interests.
4. Once the assessment has been completed, any serious health/safety issues discovered should be discussed with the homeowner prior to leaving. Tell homeowners you will be happy to discuss other IAQ issues with them when you return to collect the data. (Though it is likely the homeowner may consciously begin thinking about what activities they do, ideally we want them to continue their normal lifestyles thru the monitoring period. So, we should reserve recommending things like operating their ventilation fans, for the post visit.)
5. Schedule the time and date with the homeowner to retrieve the data. We should stay within a (48 – 72 hour ?) monitoring window.

At the post visit:

1. Assist the homeowner in completing their activity survey,
2. Collect all monitoring equipment, assure all passive samplers are appropriately labeled and properly stored. Note location of all equipment, problems, etc…
3. Inform the homeowner of their house ID number and let them know they can see their results on the web, or contact ABSN. Leave the homeowner the IAQ publication we will provide, thank them for their participation.
4. Take an outdoor CO and particle sample when leaving the home. Record results on assessment survey.

Appendix II: Indoor Air Monitoring Data Sheet

Name of Resident ____ **House ID #:** _________

House Location ____ **Date:** __________ **Time:**_____

GENERAL HOME DESCRIPTION:

Type of Residence: ☐Detached Single Family ☐ 2-4 unit Multi-Family ☐ Zero Lot Line ☐ Mobile Home

Foundation Type: ☐Heated Crawl ☐ Unheated Crawl ☐ Walkout Basement ☐ Full Basement ☐ Post & Pad
☐ Split Entry ______________ ☐ Other ______________

House Height: ☐One Story ☐ 1 ½ Story ☐ 2-3 stories ☐ Other ____________

Comments:

HEATING SYSTEM:

Type of Heating System: ☐ Forced Air ☐ Hot Water Baseboard ☐ Radiant Floor ☐ Other _____________

Heating System Fuel: ☐ Nat Gas ☐ Fuel Oil ☐ Electric ☐ Other _____________

Location of Heating System: ☐ House ☐ Garage ☐ Crawl space ☐ Basement ☐ Other __________

Furnace Filter Type: ☐ Regular ☐ Pleated ☐ High Efficiency

Combustion Venting: ☐ Natural ☐ Power-Vented ☐ Direct-Vent ☐ Other _____________

Source of Combustion Air (if not direct vent): ☐ Air leakage ☐ Combustion Air Opening

Comments:

OTHER COMBUSTION APPLIANCES:

Appliance: 1. Water Heater 2. 3. 4.	**Location**[1]	***Fuel***	***Type***[2]	***Combustion Venting***[3]	***Combustion Air***[4]
[1]. Location: Living/Garage/Crawl/Basement; [2]: Type of Water Heater: Tank/Indirect/Demand [3]. Combustion Venting: Natural/Power vent/Direct Vent; [4]. Combustion Air Source: Direct vent/air leakage/combustion air opening					

VENTILATION SYSTEM(S)

Intermittent Vented Exhaust Fans : ☐ None ☐ Bath ☐ Kitchen ☐ Garage ☐ Other _______________

Ventilation System: ☐ None ☐ Central Exhaust - No Supply ☐ Central Exhaust With Passive Vents
☐ Central Exhaust With Skuttle to furnace ☐ HRV ☐ Balanced non-HRV
☐ Other_______________________________________

Location of Central Exhaust: ☐ Bath ☐ Kitchen ☐ Main Living Area ☐ Basement ☐ Other _________

Location of Ventilation Supply: ☐ Bedrooms ☐ Main Living Area ☐ Basement ☐ Other______________

Mechanical Ventilation Estimated CFM ____________

Mechanical Ventilation Controls: ☐ Timer ☐ De-humidistat ☐ AirTrac/ Humidtrac ☐ Other__________

Crawlspace Ventilation:
☐ Passive/vents open ☐ Passive/vents closed ☐ Mechanical Vent w/de-humidistat
☐ Mechanical Vent wo / de-humidistat ☐ HRV Supply ☐ HRV Exhaust

NOTES:

GARAGE CHECKLIST:

☐ Attached Garage ☐ Detached Garage ☐ Tuck-under Garage ☐ Carport ☐ Other

Airtightness Between House and Garage: ☐ Well-sealed ☐ Typical ☐ Leaky ☐ N/A

Furnace Duct Sealing: ☐ Well-sealed ☐ Typical ☐ Very Leaky ☐ No Ducting

Garage/House Man-door well sealed? ☐ Yes ☐ No **Additional pet door/windows?** ☐ Yes ☐ No

Motor Vehicles parked in attached garage or below house? ☐ Yes ☐ No Number: ____

Vehicle ID #1 ______________________________ (License Plate, VIN or Make/Model/Year)

Vehicle ID #2 _______________________________(License Plate, VIN or Make/Model/Year)

Vehicle ID #2 _______________________________(License Plate, VIN or Make/Model/Year)

Gasoline/Solvent Usage and Storage (Check all that apply)

☐ Fuel or small engines stored in garage

☐ Solvent or fuel containers opened in garage or residence within 3 days

☐Interior painting during past 2 weeks?

☐ Other related activities:

MOISTURE CHECKLIST:

Describe building features that may affect moisture sources, moisture damage, etc.	**Yes**	**No**	**Some**	**Unknown N/A**
1. Ground next to house on all sides is sloped so as to drain water away from the house				
2. House has gutters that drain 5 ft+ away from house				
3. Foundation walls are adequately insulated?				
4. Floor area of crawl space is covered by a moisture barrier?				
5. Is standing water visible inside the crawl space?				
6. Is a sump pump/pit installed ?				
7. Condensation on water pipes or signs of moisture on wood adjacent to pipes?				
8. Moisture damage at rim joist areas?				
9. Do you notice a significant musty smell? A. Basement				
B. Crawlspace				
C. Living Area				
D. Bathroom				
E. Garage				
F. Other				
10. Is there visible mold or fungus growth?				
A. Basement				
B. Crawlspace				
C. Living Area				
D. Garage				
E. Bathroom				
F. Other				
11. Carpeting over unheated concrete floor?				

PARTICULATE CHECKLIST: Building Sources

CARPET	**Removable Rug**	**Short Pile**	***Medium Pile***	**High Pile**	**Non e**	**AreaTraffic: Light/Medium, Heavy**
Living Room						
Bedrooms						
Dining Area						
Hallways						
Basement on slab						

Other:

☐ Exposed Fiberglass Location:___________ ☐ Other ______________Location: ___________

IAQ Field Monitoring Equipment Data Sheet

House ID #: _________

Equipment Kit # ______

Owner Name:________________________**Street Address:** ____________________________

Start Date: __________ **Time:** __________ **End Date:** __________ **Time:** __________

I. OUTDOOR CONDITIONS

1. Particulates: At Start of Monitoring: PM1___ PM2.5____ PM 7___ PM10____ TSP____
At End of Monitoring: PM1___ PM2.5____ PM 7___ PM10____ TSP____
2. CO: At Start of Monitoring______________At End of Monitoring _____________
3. Temperature: At Start of Monitoring______________At End of Monitoring _____________

II. INDOOR TEMPERATURE/HUMIDITY MONITORING

House HOBO No. __________ **Location:**______________________________ **Comments:**	**Crawl/Basement HOBO No.** ________ **Location:**______________________________ **Comments:**
Other:__________**Serial No.** __________ **Location:**______________________________ **Comments:**	**Other:**_____________**Serial No.** __________ **Location:**______________________________ **Comments:**

III. INDOOR CO MONITORING

House Drager ID No. __________	**Garage Drager ID No.**___________
Location:	**Location:**
Comments:	**Comments:**

IV. BENZENE MONITORING

House Badge Serial No. __________	**Garage Badge Serial No.**___________
Badge Location	**Badge Location:**
Comments:	**Comments:**

VI. PARTICULATE MONITORING

Counter ID: _________ **Location of Instrument:**_________________________________

Comments:

VII. PRESSURE DIAGNOSTICS

Garage WRT House: Furnace Fan On______Pa Furnace Fan Off ______Pa

Other:
__________**WRT** __________**:Furnace Fan On______ Pa Furnace Fan Off ______Pa**
__________**WRT** __________**:Furnace Fan On______ Pa Furnace Fan Off ______Pa**

Comments:

Appendix III: Homeowner Survey

GENERAL INFORMATION

1. Homeowner Name:

2. Street Address: ____
3. Mailing Address: ____
4. Legal Address: ____

5. What year was your home built? ____________

6. Number of Occupants: Adults:___________ (over 65 yrs) __________ (under 65),Teens ______ (12-19) Children____ (5-11) Toddlers____ (<5)

7. Is anyone normally confined to the house more than 12 hours per day? ☐ YES ☐ NO
If so, are they: ☐ Under 4 ☐ Over 65

8. Household Pets: # Dogs _______ # Cats ___________ Other:_____________
Fish Aquarium ☐ 10-20 gallon ☐ 55 gallon ☐ Over 55 gallon

VENTILATION

9. Would you describe the general air quality in your home as:
☐ Good ☐ Average ☐ Poor ☐ Very bad

10. Do you think that your house is leaky enough to provide the fresh air you need ? ☐ YES ☐ NO

11. Are there things you sometimes do to get fresh air into your house? ☐ YES ☐ NO
What? __________________________ ☐ Always ☐ Often ☐ Occasionally ☐ Never
__________________________ ☐ Always ☐ Often ☐ Occasionally ☐ Never

12. Do any of the following affect the quality of the outside air available to your home?
☐ Windblown dust
☐ Traffic fumes
☐ Neighborhood activities (Describe ___________________)

13. Are there outdoor air vents in some of the rooms in your home? (These vents usually come through the wall or are part of the window frame.) ☐ YES ☐ NO
How often are they opened? ☐ Always ☐ Often ☐ Occasionally ☐ Never

14. Does your house have a mechanical ventilation system to bring in outside air? ☐ YES ☐ NO

(If "NO", skip to #26.)

15. ☐ YES ☐ NO Do any exhaust fans in your home run continuously, or do they sometimes come on automatically?

16. ☐ YES ☐ NO Do you have a permanently mounted controls for your ventilation system?

17. ☐ YES ☐ NO Is your ventilation system working as well now as when you moved in? If not, why?

18. ☐ YES ☐ NO Has your ventilation system been repaired? What part needed repair?__________

19. Have you modified the ventilation system by:
☐ YES ☐ NO Adjusting the timer (to change hours of operation)
☐ YES ☐ NO Adjusting the fresh air intake damper near the furnace
☐ YES ☐ NO Disconnecting the timer
☐ YES ☐ NO Adjusting wall or window vents
☐ YES ☐ NO Other modification?

20. How frequently is your ventilation system maintained? (Do not include changing furnace filters.)
☐ Never
☐ Rarely-only when something is not working
Œ Regularly, at start of each heating season

	□ Often-at the beginning and end of each heating system
21.	Who does the maintenance on your ventilation system? □ Self □ HVAC Contractor □ Friend □ No one
22.	Do you shut the ventilation system off at times during the year? □ No □ Yes Why, and for how long? ________________________________
23.	How many hours a day does your ventilation system run? □ Never □ < 2 hours □ 2-4 hours □ 4-6 hours □ 6-10 hours □ >10 hours □ Don't know
24.	How much do the following factors limit how much your ventilation system operates: (Check all that apply) a. Drafts: □ Not at all □ Somewhat □ Important □Very important b. Energy Costs: □ Not at all □ Somewhat □ Important □Very important c. Noise: □ Not at all □ Somewhat □ Important □Very important d. Low Relative Humidity: □ Not at all □ Somewhat □ Important □Very important
25.	If you had a choice, would you want a ventilation system similar to the one you have now in your home? □ YES □ Maybe □ NO □ I don't know

MOISTURE LEVELS	
26.	How many plants do you have in your home?
27.	□ None □ 5 or less □ 6-10 □ more than 10
28.	Do your home have: o Humidifier: Type: ________________ Location: ___________ Usage:__________ o Dehumidifier: Type: ________________ Location: ___________ Usage:__________
29.	How much ice buildup do you have on your windows in winter? □ None □ Minor (less than 1 inch at bottom of window glass) □ Ice sometimes on glass and part of window sill □ Extensive icing at times: whole sill covered with ice, and at other locations on sash or frame
30.	Does the ice build up and last all or most of the winter? □ YES □ NO
31.	Can you operate your windows all winter – open and close them? □ YES □ NO
32.	Do you ever have problems operating your front or back door lock set? □ YES □ NO
33.	Have your entry doors ever refused to open in the winter? □ YES □ NO
34.	Have you ever noticed staining from rust on the door and door jamb around the hinges on your outside doors? □ YES □ NO
35.	Are crawlspace vents opened and closed seasonally? □ Yes □ No □ Not Applicable
36.	Are you aware of any previous plumbing leaks in your home? □ YES □ NO
37.	Are you aware of any previous roof leaks or ice damming? □ YES □ NO
38.	Are you aware of any previous flooding of the crawlspace or basement? □ YES □ NO

STRENGTH OF INDOOR CONTAMINANTS
39. Are there noticeable combustion odors in your home? ☐ Never ☐ Seldom ☐ Often ☐ Always
40. Are there molds or musty odors in your home? ☐ Never ☐ Seldom ☐ Often ☐ Always
41. Is the humidity level unusually high or is moisture noticeable on windows or other surfaces? ☐ Never ☐ Seldom ☐ Often ☐ Always
42. Is the humidity level unusually low? ☐ Never ☐ Seldom ☐ Often ☐ Always
43. Does the air often seem stale? ☐ Never ☐ Seldom ☐ Often ☐ Always
44. Is the house temperature unusually warm or cold? ☐ Never ☐ Seldom ☐ Often ☐ Always
45. Do you have a CO detector? ☐ Yes ☐ No
46. Has the CO detector alarm ever gone off? ☐ Yes ☐ No Why? ________________________

HEALTH CONCERNS
47. Does anyone suffer from: ☐ asthma ☐ heart problems ☐ Other respiratory ailments? ☐ bronchitis ☐ allergies
48. Do any members of your family often suffer from any of the following symptoms: ☐ headaches ☐ itchy or watery eyes, ☐ nose or throat infection or dryness ☐ dizziness ☐ dizziness ☐ nausea ☐ colds
49. Have you noticed whether these problems are worse in winter? ☐ YES ☐ NO
CLEANING EQUIPMENT
50. Vacuum Type: ☐ Portable Vac: ☐ Central Vac Air Filter: ☐ Typical ☐ HEPA
51. Dedicated Air Cleaners: ☐ None ☐ Room (Type_________) ☐ Whole House
52. What type of furnace filter do you use? ☐ Standard ☐ Pleated ☐ HEPA filter ☐ Other_____
53. How often do you replace the furnace filter? ☐ 1-2 months ☐ 6-12 months ☐ Seldom ☐ Never
COOKING EQUIPMENT
54. Cook Stove Type: ☐ Gas ☐ Electric ☐ Other
55. Range Hood Type: ☐ Standard ☐ Downdraft (JennAire type) ☐ Commercial
56. Range hood vented to outdoors? ☐ Yes ☐ No

NOTES:

Homeowner Survey: Post-Monitoring

Household Activities:

1. How often did you operate your ventilation system during the monitoring period?
   Bath fan: □ Never □ < 2 hrs/day □ 2-8 hrs/day □ 8-12 hrs/day □ More than 12 hrs/day
   Kitchen fan: □ Never □ < 2 hrs/day □ 2-8 hrs/day □ 8-12 hrs/day □ More than 12 hrs/day
   Whole house fan: □ Never □ < 2 hrs/day □ 2-8 hrs/day □ 8-12 hrs/day □ More than 12 hrs/day

2. Did you clean the house during the monitoring period?
   □ No vacuuming/sweeping □ Every day □ Every other day

3. What type of cleaning equipment do you most often use:
   □ Broom □ Standard Upright / Canister Vac □ Vac with HEPA filter □ Central Vac

4. Did you use a humidifer during the monitoring period? □ Yes □ No

5. Use of motor vehicles during the monitoring period was: □ Low □ Normal □ High ____ Average times per day _______

6. Can you give us an estimate of the number of times the garage man-door was opened during the monitoring period? □ Never □ Hardly ever □ Most of the time □ Always _

7. Did you operate any unvented combustion appliances during the monitoring period? □ Yes □ No

8. Did you operate a wood fireplace or wood stove during the monitoring period? □ No □ Yes ___ hrs.

9. Did anyone in your household smoke inside your home? □ Never □ Seldom □ Often

10. If the answer to #9 was "Yes" where did they smoke? □ in one room only □ anywhere in the house

11. Did you operate the ventilation system during the monitoring period?
    □ Never □ Hardly ever □ Most of the time □ Always

12. Did household members engage in any of the following hobbies in your home: woodworking, jewelry making, pottery making, painting, photography, soldering, welding gluing, or model building? □ No □ Yes (What?____)

13. How often do you use your range vent when cooking: □ Never □ Seldom □ Usually □ Always

14. Do you use the range vent when baking? □ Yes □ No

15. If you do not use your range hood, why not: □ Noise □ Don't need it □ Other _____________

16. Were cooking activities during the monitoring period fairly standard for your home?
    □ Yes □ No (What was different?____)

Appendix IV. Benzene Validation Study

Values are in ppbv.

		1/13/2002 badge 3740	1/14/2002 badge 3793	sd	precision CV
house	Benzene	20	20	0	0%
	Toluene	30	30	0	0%
	Ethylbenzene	20	20	0	0%
	Xylene	40	40	0	0%
		badge 3790	badge 3826		
garage	Benzene	100	100	0	0%
	Toluene	300	300	0	0%
	Ethylbenzene	20	20	0	0%
	Xylene	90	70	14	18%
				average	2%

consecutive 24-hr canister average	badge average	std	accuracy CV	
8	20	9	63%	
24	30	4	16%	
2	20	12	110%	subset ave.
11	40	20	80%	67%
166	100	46	35%	
214	300	61	24%	
41	20	15	49%	subset avg.
200	80	85	61%	42%
		average	55%	

Precision:

The precision average of 2%, comparing collocated badges, was well within the standard criterion of 25% coefficient of variation (CV). This shows that the method gives reproducible results to a very high degree.

Accuracy:

Using collocated canister results as the "standard" for the determination of badge result accuracy, the average of 55% may look bad, but we are comparing two different methods of sample collection as well as analysis, so a difference is expected, especially when the canister results cost $370 and the badge analysis cost $75. In support of the general acceptability of badge analyses being used in the future in place of canister analyses, badge results on lower concentrations were higher than the canister results, but not alarmingly so, while badge results on higher concentrations were both lower and higher than the standard, showing little bias, but with better accuracy, as one would expect with higher concentrations. The University of Alaska, Anchorage lab has developed the badge method so that an analysis for benzene alone costs $25. A comparable cost for a benzene canister analysis would probably be over $200. This further supports badge use. Generally, if low concentrations, near the detection level, are received, they can be thought of as perhaps higher than accurate, which, at those concentrations, do not indicate that there is a problem. Further work by the UAA lab may be able to lower the detection limit, as well. Conversely, if high concentrations are received, they can be thought of as being worthy of further concern, as they should be. If funding becomes available, a blind audit of the badge method should be conducted to determine its accuracy using the same method of analysis, rather than a different method, which was convenient in this study.

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APPENDIX V: SURVEY OF AIR QUALITY GUIDELINES

National Ambient Air Quality Standards (NAAQS)

The Clean Air Act, which was last amended in 1990, requires EPA to set national Ambient Air Quality Standards, for pollutants considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings.

The EPA Office of Air Quality Planning and Standards has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" pollutants. They are listed below.

Pollutant	Standard Value	Standard Type
Carbon Monoxide (CO)		
8-hour Average	9 ppm (10 mg/m³)	Primary
1-hour Average	35 ppm (40 mg.m³)	Primary
Nitrogen Dioxide (NO_2)		
Annual Arithmetic Mean	0.053 ppm (100 µg/m³)	Primary and Secondary
Ozone (O_3)		
1-hour Average	0.12 ppm (234 µg/m³)	Primary and Secondary
8-hour Average	0.08 ppm (157 µg/m³)	Primary and Secondary
Lead (Pb)		
Quarterly Average	1.5µg/m³	Primary and Secondary
Particulate (PM10)		
Annual Arithmetic Mean	50 µg/m³	Primary and Secondary
24- hour Average	150 µg/m³	Primary and Secondary
Particulate (PM 2.5)		
Annual Arithmetic Mean	15 µg/m³	Primary and Secondary
24-Hour Average	65 µg/m³	Primary and Secondary
Sulfur Dioxide (SO_2)		
Annual Arithmetic Mean	0.03 ppm (80 µg/m³)	Primary and Secondary
24-hour Average	0.14 ppm (365 µg/m³)	Primary and Secondary
3-hour Average	0.50 ppm (1300 µg/m³)	Primary and Secondary

** The ozone 8-hour standard and the PM 2.5 stnadards are included for information only. A 1999 federal court ruling blocked implementation of these standards, which EPA proposed in 1997. EPA has asked the U.S. Supreme Court to reconsider that decision. The Updated Air Quality Standards website has additional information.

Source: www.epa.gov/airs/criteria.html
EPA Clean Air Act National Ambient Air Quality Standards

Allowable (Legal) Limits for CO:

Occupational Safety & Health Administration, USA (OSHA) (for industrial situations) -

Permissible Exposure Limit (PEL, by TWA) - 50 ppm, 8 hrs.
Old PEL Standard (by TWA) - 35 ppm, 8 hrs.
Threshold Limit Value (TLV, by TWA) - 25 ppm (29 mg/cu. m)
(recommended by American Conference of Governmental & Industrial Hygienists [**ACGIH**]
Ceiling (max. value, 15 min.) - 200 ppm (229 mg/cu. m)

Michigan Occupational Safety & Health Administration (MIOSHA) -

PEL (Industry, by TWA) - 35 ppm, 8 hrs. (38.5 mg/cu. m)
PEL (Construction, by TWA) - 50 ppm, 8 hrs. (55 mg/cu. m)
Ceiling (max. value) - 200 ppm (229 mg/cu. m)

Environmental Protection Agency, USA (EPA) -

Domestic, outdoor air, all ages (TWA) - 9 ppm*, 8 hrs.
Domestic, outdoor air, all ages (TWA) - 35 ppm, 1 hr.

World Health Organization (WHO) -

Domestic, outdoor air, all ages (TWA) - 9 ppm*, 8 hrs.

American Gas Association -

Indoor air (leakage at a heat register) - 15 ppm

American Society of Heating, Refrigeration & Air Conditioning Engineers (ASHRAE) -

Indoor air (leakage at a heat register) - 9 ppm

Common Action Level -

Indoor air (most common CO level triggering action by local Authorities of Jurisdiction) - 9 ppm

TWA - Computed by making measurements at intervals over 8 hours, then adding the sums of the concentrations and the intervals, and dividing by 8 hours (480 min.).

** Based on several published studies of people with coronary ischemic disease showing ECG changes during moderate exercise when breathing concentrations of CO giving 3% COHb.*

American National Standards Institute (ANSI Z21.1) -

Max. CO conc. allowed from an unvented space heater ("air-free") - 200 ppm
Max. CO conc. allowed in a furnace flue gas ("air-free") - 400 ppm
Max. CO conc. allowed for emissions from an unvented gas oven ("air-free") - 800 ppm

"air-free" refers to the concentration of CO in combustion gases undiluted with flue, or other gases containing little CO. "air-free" values may be computed using a equation that takes into account the O_2 concentration of the flue gas.

American Conference of Governmental Industrial Hygienists, Inc.: The history of Threshold Limit Values (TLV) from this group has been to continually lower the values as more information about the effects of CO on humans has become available. The current intent is to keep COHb below 3.5%, since many deleterious neurobehavioral effects have been reported above this COHb level.

1946 - 1947: MAC-TWA = 100 ppm
1946 - 1966: TLV-TWA = 100 ppm
1965: TLV-TWA = 50 ppm (proposed)
1967: TLV-TWA = 50 ppm
1976: TLV-STEL = 400 ppm
1991: TLV-TWA = 25 ppm (proposed)
present TLV-TWA = 25 ppm

Other Nations:

Australia: TWA = 50 ppm, STEL = 400 ppm
Fed. Republic of Germany: TWA = 30 ppm, 60 ppm for 30 minutes.
Sweden: TWA = 35 ppm, 100 ppm for 15 minutes.
United Kingdom: TWA = 50 ppm, STEL = 300 ppm (10 minutes)

The **Indoor Air Quality Association** (IAQA) is a nonprofit, multi-disciplined organization, dedicated to promoting the exchange of indoor environmental information, through education and research, for the safety and well being of the general public.

IAQA has consolidated the many different standards, guidelines, reports and study recommendations regarding indoor air quality into one useful document: IAQA 01-2000, *Recommended Guidelines for Indoor Environments*. The handy 12-page reference tool boils down the key indoor air recommendations and requirements of organizations like ASHRAE, WHO, EPA, Health and Welfare Canada, several U.S. states and prestigious academic institutions. Shown below is the "Quick Reference Guide" to the main points covered in detail within IAQA 01-2000.

Quick Reference Guide to IAQA 01-2000
Recommended Guidelines for Indoor Environments

IAQA 01 Section #	Parameter	Limit/Range	References
Physical Parameters			
1.1	Temperature	Summer 73-79 F; Winter 68-74.5 F	ASHRAE 55
1.2	Relative Humidity	30%-65%	Florida Dept. Man. Ser.
1.3	Air Movement	0.8 ft/s or 0.25 m/s	WHO
2.0	Ventilation (Carbon Dioxide)	650 over ambient	ASHRAE 62
3.0	Filtration	25%-30% Dust Spot Efficiency	ASHRAE 52.1
4.0	Pressurization	1-5 Pascals &/or + Press	Florida Solar Energy Center; Lstiburek
5.1	Respirable Particulate	50 mg/m3	State of California, Air Resources Board
5.2	Particulate in Cleaned HVAC Systems	1.0 mg/100 cm2	NADCA 1992-01
Chemical Parameters			
6.1	Carbon Monoxide	9 ppm	EPA - National Ambient Air Quality Standard
6.2	Radon	4 picoCuries/liter	EPA
6.3	Ozone	0.05 ppm	WHO
7.1	Total Volatile Organic Compounds	3 mg/m3 (0.64 ppm)	Molhave, 1990
7.2	Formaldehyde	0.06 mg/m3 (0.05 ppm)	Health & Welfare Canada
Biological Parameters			
8.1	Fungal Bioaerosols (culturable)	300 CFU/m3 total; 50 CFU/m3 individual (excepting Cladosporium)	Robertson, 1997
8.2	Bacterial Bioaerosols (culturable)	500 CFU/m3 total; dominated by gram + organisms	WHO

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Health Canada: Exposure Guidelines for Residential Indoor Air Quality

Summary of Exposure Guidelines

Contaminant	Acceptable Short-Term Exposure Range: ASTER	Acceptable Long-Term Exposure Range: ALTER
Carbon Dioxide		≤ 6300 mg/m3 (≤ 3500 ppm)
Carbon Monoxide	≤ 11 ppm – 8 hr ≤ 25 ppm – 1 hr	-
Formaldehyde	**Action Level**: 120 μg/m³ (≤0.12 ppm)	**Target Level**:60 μg/m³ (≤0.12 ppm)
Nitrogen Dioxide	≤480 μg/m³ (≤0.25 ppm) -1 hr	≤100μg/m³ (≤0.05 ppm)
Ozone	≤240 μg/m³ (≤0.12 ppm)- 1 hr	-
Particulate Matter (PM 2.5)	≤100 μg/m³ - 1hr	≤40 μg/m³
Sulphur Dioxide	≤1000 μg/m³ (≤0.38 ppm)- 5 min	≤50 μg/m³ (≤0.019 ppm)
Water Vapor	30-80% R.H -summer 30-55% R.H – winter (unless constrained by window condensation)	-
Radon		

BENZENE: Agency For Toxic Substances & Disease Registry

Minimal Risk Levels (MRLs) for Hazardous Substances

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [42 U.S.C. 9604 et seq.], as amended by the Superfund Amendments and Reauthorization Act (SARA) [Pub. L. 99-499], requires that the Agency for Toxic Substances and Disease Registry (ATSDR) develop jointly with the U.S. Environmental Protection Agency (EPA), in order of priority, a list of hazardous substances most commonly found at facilities on the CERCLA National Priorities List (NPL) (42 U.S.C. 9604(i)(2)); prepare toxicological profiles for each substance included on the priority list of hazardous substances, and to ascertain significant human exposure levels (SHELs) for hazardous substances in the environment, and the associated acute, subacute, and chronic health effects (42 U.S.C. 9604(i)(3)); and assure the initiation of a research program to fill identified data needs associated with the substances (42 U.S.C. 9604(i)(5)).

The ATSDR Minimal Risk Levels (MRLs) were developed as an initial response to the mandate. Following discussions with scientists within the Department of Health and Human Services (HHS) and the EPA, ATSDR chose to adopt a practice similar to that of the EPA's Reference Dose (RfD) and Reference Concentration (RfC) for deriving substance-specific health guidance levels for non-neoplastic endpoints. An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors and other responders to identify contaminants and potential health effects that may be of concern at hazardous waste sites. **It is important to note that MRLs are not intended to define clean-up or action levels for ATSDR or other Agencies.**

The toxicological profiles include an examination, summary, and interpretation of available toxicological information and epidemiologic evaluations of a hazardous substance. During the development of toxicological profiles, MRLs are derived when ATSDR determines that reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure to the substance. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. Inhalation MRLs are exposure concentrations expressed in units of parts per million (ppm) for gases and volatiles, or milligrams per cubic meter (mg/m3) for particles. Oral MRLs are expressed as daily human doses in units of milligrams per kilogram per day (mg/kg/day). Radiation MRLs are expressed as external exposures in units of millisieverts.

ATSDR uses the no-observed-adverse-effect-level/uncertainty factor (NOAEL/UF) approach to derive MRLs for hazardous substances. They are set below levels that, based on current information, might cause adverse health effects in the people most sensitive to such substance-induced effects. MRLs are derived for acute (1-14 days), intermediate (>14-364 days), and chronic (365 days and longer) exposure durations, and for the oral and inhalation routes of exposure. Currently MRLs for the dermal route of exposure are not derived because ATSDR has not yet identified a method suitable for this route of exposure. MRLs are generally based on the most sensitive substance-induced end point considered to be of relevance to humans. ATSDR does not use serious health effects (such as irreparable damage to the liver or kidneys, or birth defects) as a basis for establishing MRLs. Exposure to a level above the MRL does not mean that adverse health effects will occur.

MRLs are intended to serve as a screening tool to help public health professionals decide where to look more closely. They may also be viewed as a mechanism to identify those hazardous waste sites that are not expected to cause adverse health effects. Most MRLs contain some degree of uncertainty because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, and nutritionally or immunologically compromised) to effects of hazardous substances. ATSDR uses a conservative (i.e., protective) approach to address these uncertainties consistent with the public health principle of prevention. Although human data are preferred, MRLs often must be based on animal studies because relevant human studies are lacking. In the absence of evidence to the contrary, ATSDR assumes that humans are more sensitive than animals to the effects of hazardous substances that certain persons may be particularly sensitive. Thus the resulting MRL may be as much as a hundredfold below levels shown to be nontoxic in laboratory animals. When adequate information is available, physiologically based pharmacokinetic (PBPK) modeling and benchmark dose (BMD) modeling have also been used as an adjunct to the NOAEL/UF approach in deriving MRLs.

Proposed MRLs undergo a rigorous review process. They are reviewed by the Health Effects/MRL Workgroup within the Division of Toxicology; and expert panel of external peer reviewers; the agency wide MRL

Workgroup, with participation from other federal agencies, including EPA; and are submitted for public comment through the toxicological profile public comment period. Each MRL is subject to change as new information becomes available concomitant with updating the toxicological profile of the substance. MRLs in the most recent toxicological profiles supersede previously published levels. To date, 118 inhalation MRLs, 183 oral MRLs and 6 radiation MRLs have been derived. A listing of the current published MRLs by route and duration of exposure is provided as follows.

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ATSDR MINIMAL RISK LEVELS (MRLs)

December 2001

ATSDR MINIMAL RISK LEVELS (MRLs)

Name CAS Number	Route	Duration	MRL	Factors	Endpoint	Final	Date
BENZENE 000071-43-2	Inh.	Acute	0.05 ppm	300	Immuno.	Final	09/97
		Int.	0.004 ppm	90	Neurol.		

OSHA Regulations for Benzene

Time-weighted average limit (TWA). The employer shall assure that no employee is exposed to an airborne concentration of benzene in excess of one part of benzene per million parts of air (1 ppm) as an 8-hour time-weighted average.

Short-term exposure limit (STEL). The employer shall assure that no employee is exposed to an airborne concentration of benzene in excess of five (5) ppm as averaged over any 15 minute period.

[1] Schlapia, A. and Morris, S., Architectural, Behavioral an Environmental Factors Associated with VOCs in Anchorage Homes 98-A504; Anchorage Air Pollution Control Agency, Anchorage, Alaska, 1998.

[2] Wallace LA, Pellizzari ED, Hartwell T, Perritt K, Ziegenfus R. Exposures to benzene and other volatile organic compounds from active and passive smoking. Arch Environ Health 42:272-279 1987.

[3] Benzene - The Tenth Report on Carcinogens. U.S. Department of Health and Human Services Public Health Service National Toxicology Program (2002), 2.0 MB PDF, 6 pages. This is a document that explains the carcinogenicity, properties, use, production, exposure, and regulations regarding benzene.

[4] Wallace LA. The TEAM Study: Summary and Analysis. Vol 1. EPA 600/6-87/002a. NTIS PB 88-100060. Washington:U.S. Environmental Protection Agency, 1987.

[5] IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Some Industrial Chemicals and Dyestuffs. Vol. 29. 416 pp. Lyon, France: IARC, 1982.

[6] Toxicological profile for benzene. Agency for Toxic Substances and Disease Registry (ATSDR). 1997. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service

[7] Department of Environment. Expert Panel on Air Quality Standards, Benzene), London, Ontario, CA, 1994.

[8] Minimal Risk Levels (MRLs) for Hazardous Substances. Agency For Toxic Substances and Disease Registry. 2001.

[9] Minimal Risk Levels (MRLs) for Hazardous Substances Agency for Toxic Substances and Disease Registry (ATSDR); Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service; 2003.

[10] Schlapia, A. and Morris, S., Architectural, Behavioral an Environmental Factors Associated with VOCs in anchorage Homes 98-A504; Anchorage Air Pollution Control Agency, Anchorage, Alaska, 1998.

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[13] The Inside Story: A Guide to Indoor Air Quality. United States Environmental Protection Agency and theUnited States Consumer Product Safety Commission Office of Radiation and Indoor Air (6604J) EPA Document # 402-K-93-007, April 1995.

[14] The Inside Story: A Guide to Indoor Air Quality. United States Environmental Protection Agency and theUnited States Consumer Product Safety Commission Office of Radiation and Indoor Air (6604J) EPA Document # 402-K-93-007, April 1995.

[15] Gosink, Tom. What Do Carbon Monoxide Levels Mean? Alaska Science Forum Article #588; January 28, 1983. Geophysical Institute, University of Alaska Fairbanks.

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[17] Penney, David G, Ph.D. Ed., Carbon Monoxide Toxicity. CRC Press, June, 2000.

[18] CO - How Carbon Monoxide Affects the Way We Live and Breathe. US Environmental Protection Agency, Office of Air Quality Planning & Standards November 2000.

[19] National Ambient Air Quality Standards. EPA Office of Air Quality Planning & Standards, following Clean Air Act of 1990

[20] EPA'S Revised Particulate Matter Standards, U.S. Environmental Protection Agency, July 1997

[21] Health Canada; Exposure Guidelines for Residential Indoor Air Quality A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health; July 1989.

[22] Schwartz, Joel, Assessing Life-Shortening Associated with Exposure to Particulate Matter, Harvard University 2000

[23] Freeman, John, Report on Carbon Monoxide Monitoring Study For Alaska Housing Finance Corporation, Alaska Housing Finance Corporation, 2000.

[24] Schlapia, A. and Morris, S., Architectural, Behavioral an Environmental Factors Associated with VOCs in Anchorage Homes 98-A504; Anchorage Air Pollution Control Agency, Anchorage, Alaska, 1998.