Architectural, Behavioral and Environmental Factors Associated with VOCs in Anchorage Homes

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ABSTRACT

Indoor air samples were collected in 137 Anchorage homes between December 1994 and February 1996 to determine which household characteristics were associated with elevated benzene, ethyl benzene, toluene, and xylene (BETX) concentrations. Integrated 24-hour samples were collected on a one-in-twelve day schedule using evacuated Summa® canisters and analyzed by EPA method TO-14 The geometric mean in-home benzene concentration was 4.1 ppbv and the arithmetic mean concentration was 15.8 ppbv. About one-fourth of the homes sampled had benzene concentrations above 10 ppbv. Statistical techniques were used to relate benzene concentrations to variables describing architectural, behavioral, and environmental characteristics in the homes sampled. Because BETX measurements were not normally distributed, the data were transformed using a $\log_e$ transformation prior to statistical analysis. The presence of an attached garage was the factor most strongly associated with in-home benzene. Elevated benzene was also strongly related to the use of a garage to park vehicles or store fuel or small engines. Higher benzene levels were found in homes with living space located over the garage. Homes with forced air furnaces had significantly higher benzene levels than those with hot water boilers. In homes with an attached garage, tobacco smoking was not associated with benzene. In homes without attached garages, however, $\log_e$ benzene concentrations were about twice as high as those in nonsmoking homes. This difference approached statistical significance.

INTRODUCTION

It has been widely observed that indoor concentrations of volatile organic compounds (VOCs) are substantially higher than ambient concentrations. Lance Wallace of the EPA conducted a major study of indoor benzene in the late 1980's. (1) The objective of this study, known as the Total Exposure Assessment Methodology (TEAM) Study, was to identify the major sources of benzene exposure for the U.S. population. Wallace and his associates sampled indoor air and water and took breath samples from about 800 persons in the course of this work. Wallace concluded that indoor benzene levels are nearly always greater than ambient levels and outweigh the contributions of outdoor air to human exposure. Large point sources such as gas stations and industrial sites are perceived by the public as major sources of exposure, but they contribute little to the exposure of the population as a whole.

The potential for indoor exposure may be higher in Anchorage and in other cold climates because of tighter homes and the tendency for residents to stay inside during cold weather. A previous Anchorage study, concluded in 1994, indicated that ambient VOC concentrations in

Anchorage were higher than many other urban areas in the U.S. (2) Although this study focused primarily on the measurement of ambient or outdoor concentrations, a limited number of indoor measurements were made for comparative purposes. These measurements indicated that indoor VOC concentrations were several times higher than ambient concentrations. In some homes benzene concentrations were found to be two orders of magnitude higher than those measured in the ambient air. Although household characteristics were not rigorously documented in the 1994 study, the data suggested a strong association between attached garages and elevated VOCs within the homes sampled. The preliminary findings of the 1994 study sparked an interest in investigating the factors influencing VOC concentrations in Anchorage homes more thoroughly.

The purpose of this study was to determine which architectural, behavioral and environmental factors are associated with elevated concentrations of VOCs in Anchorage homes. Sampling was conducted between December 1994 and February 1996. Benzene, ethyl benzene, toluene, and xylene (BETX) concentrations were measured over a 24-hour period in a total of 137 Anchorage homes. Three or four homes were sampled every 12 days. Benzene was of particular interest due to its classification as a known (Group A) carcinogen. In addition, a survey was developed to document specific architectural, behavioral and environmental characteristics in each of the homes sampled. Relationships between these household characteristics and indoor VOC concentrations were subsequently investigated. Statistical techniques were used to determine which household characteristics were most strongly associated with elevated indoor VOCs. The influence of garage configuration, heating system type, cigarette smoking behavior, and the storage of volatile fuels and solvents within the home or garage were among the many household characteristics investigated.

The gasoline distributed in Alaska during the study period may have also increased the potential for indoor VOCs, particularly benzene. To facilitate vehicle startup in Alaska's cold climate, winter grade fuel is more volatile (Volatility Class E, Reid Vapor Pressure = 13.5 to 15 psi) than most areas of the country. The potential for evaporative emissions may be enhanced as a result of this increased volatility, especially when vehicles are stored in a heated garage. In addition, during the study period the benzene content in Alaska gasoline was two to three times higher than most areas of the U.S. Gasoline tested from the two major distributors in Anchorage had a benzene content that ranged from 2.2% to 4.5%. (3) The relatively high benzene content and volatility of Alaskan gasoline may increase benzene emissions from cars, small engines and fuel storage containers in attached garages. Although the effects of the high volatility and benzene content of Alaskan fuel were not investigated in this study, other studies suggest a relationship between gasoline benzene content and ambient concentrations. (4)

METHODOLOGY

Selection of Homes for Sampling

Because the major focus of this study was to relate VOC levels to household characteristics and not to measure population exposure, little effort was made to randomize the selection of homes sampled. Participants were solicited through many channels. Letters describing the project were left at homes or mailed to occupants of large buildings. Many of the homes sampled were found by door-to-door solicitation.

A representative sample of dwelling types (e.g. single family, duplex, multifamily, mobile home) was desired, but due to practical and logistical constraints, the number of multifamily units surveyed was less than proportionate (Fig. 1). Persons owning their homes who planned to remain living at the residence seemed more interested in participating; more transient multifamily residents tended to be less interested. Mailed inquiries, necessary in large controlled-access buildings, were less effective in attracting participants than a personal explanation of what the study hoped to accomplish.

Some bias is acknowledged concerning the choice of homes in the survey. In cold climates limited air exchange results in a build-up of pollutants indoors in the coldest months. It was assumed that evaporative and exhaust emissions from automobiles in attached garages would contribute to indoor concentrations, and these were sampled in disproportionate numbers, particularly during the winter.

A surprising number of residents declined to participate. Some feared that a high benzene concentration would require that they do expensive remediation. One homeowner declined re-testing expressly because his home was on the market. Some residents who had exposure to industrial chemicals in the workplace felt that the relative risk of benzene was small and chose not to be surveyed. Smokers, perhaps for the same reason, were underrepresented. Though smokers comprise 28% of the adult population in Alaska, only 15% of the homes in the survey had residents that smoked in the home.

BETX Sampling Methodology

Integrated 24-hour indoor air samples were collected in 137 homes in Anchorage between December 1994 and February 1996 . Evacuated six-liter Summa® canisters were deployed every twelve days in three to five homes. Canisters were equipped with flow restrictors to maintain a flow rate of about 2 ml/min. A vacuum pressure of approximately one-half atmosphere remained at the end of the sampling period to maintain flow. The operator physically opened and shut the intake valves on each canister. This sampling method was also used in the 1994 Anchorage ambient VOC study and was designed for use in severe weather conditions. Reliance on manual equipment without pumps and other mechanical equipment averted electronic failure, made weather shelters unnecessary outside, and allowed silent operation inside residences.

Canisters samplers were normally deployed in the living room where residents tended to spend most of their waking hours. Each in-home sample was paired with an ambient measurement taken at the same time near the home using an identical canister system. To reduce the number of outdoor samples required, three or four homes in close proximity were selected for sampling for each scheduled sampling period. Thus, a single outdoor monitor, located within 100 meters of each of the homes could be used to characterize outdoor or background concentrations for all of the homes sampled.

Accuracy, method reproducibility, and laboratory analytical precision met quality control guidelines established for the study. Accuracy was assessed by challenging the laboratory contractor with audit canisters containing known concentrations of BETX prepared by an independent EPA contract laboratory. The deviation between true and reported concentrations was less than 20% for all BETX analytes.

Thirty-two blind collocated pairs were analyzed during the course of the study to assess method reproducibility. Four of the five analytes met the target coefficient of variation (CV < 25%). The target CV was greatly exceeded for ethylbenzene (CV=186%). Disparate results on two of the 32 sample pairs were largely responsible for the high CV. When these two "outliers" were eliminated from the CV calculation, the CV was reduced to an acceptable 11% for this analyte.

Survey of Architectural, Behavioral, and Environmental Characteristics of Homes

The primary objective of this study was to characterize BETX concentrations in Anchorage homes and to correlate these concentrations with the architectural, behavioral, and environmental characteristics of the home environment. A survey was designed to document factors that were suspected of being related to elevated BETX concentrations. These factors included:

Architectural factors:

- dwelling type (single family, small multifamily, large multifamily, mobile home)
- the presence of attached garages containing vehicles or small engines
- mechanisms affecting airflow within the home or garage
- age of home
- size of living area (sq. ft)
- configuration of garage relative to living area
- heating system type (forced air furnace vs. hot water boiler)

Behavioral factors:

- frequency of automobile use (number of trips taken)
- age of vehicle(s) in garage
- storage of fuel or volatile chemicals in the home or garage
- cigarette smoking inside the home
- recent interior painting or remodeling
- use of fireplace, wood stove, natural gas stove during sampling periods
- duration of ventilation fans, clothes dryer use

Environmental factors:

- ambient temperature, wind speed
- ambient BETX concentration near the home
- the proximity of ambient sources of BETX (gasoline stations, major roadways)

RESULTS AND DISCUSSION

Summary of Architectural, Behavioral, and Environmental Factors in Homes Sampled

Architectural Characteristics

The average age of the 137 homes sampled was 23 years. Fifty-five percent were detached, single family homes, 22% were small multifamily units, 18% were large multifamily, and 5% were mobile homes. Living area for individual dwellings averaged 1660 ft^2. Ninety-one homes had garages attached to the home or building, and 46 had no provision for inside parking. Of the homes with attached garages, 46% had some living space above the garage.

Because of its low cost, natural gas was the primary heating fuel in 97% of the homes sampled. The remaining 3% of the homes had electric heat. In the natural gas heated homes, 66% used boilers, the others, forced air furnaces.

Behavioral Characteristics of Residents

Because motor vehicles were suspected to be a major influence on BETX levels in the home, habits related to parking and garages were well documented. Of the 91 of homes with an attached garage, 76% housed a vehicle some time during the testing period. The average number of vehicles parked in these attached garages was 1.5.

The average number of vehicle trips originating from the garage of a single family homes or from small multifamily units was two per day. The exit and re-entry (or vice versa) of a vehicle from a garage constituted one vehicle trip. There was no practical way to determine the number of vehicle trips from garages of large multifamily buildings.

Fifty-seven percent of attached garages contained fuel or small engines. Eleven percent of the residents recalled opening fuel or solvent containers in the home or garage during testing or within the prior three day period. Painting had occurred in 13% of homes within two weeks of sampling. Four percent used wood stoves or fireplaces during the testing period. Natural gas cooking stoves were used in 26% of homes sampled. In 9% of homes, ventilation fans were used for an hour or more. Twenty-seven percent of homes used the clothes dryer for an hour or more during the sampling period.

Environmental Characteristics

Environmental factors suspected of influencing indoor BETX include ambient temperature and ambient VOC concentrations, wind speed, and traffic volumes of nearby roadways. Local data from the National Weather Service were used to document ambient temperature and wind speed for sampling days. The mean ambient temperature for the days sampled was 37°F. Wind speed averaged 9 mph. Ambient benzene concentrations measured adjacent to the homes sampled ranged from 0.1 ppbv to 13.3 ppbv. The arithmetic mean ambient benzene concentration measured at outdoor locations next to the homes sampled was 1.9 ppbv.

Summary of In-Home BETX Measurements

Figure 2 displays the frequency distribution of the indoor benzene measurements. More than half of the homes sampled had benzene concentrations less than 5 ppbv. About 15% of the homes had benzene concentrations between 5 and 10 ppbv. About one-fourth of the homes sampled had benzene concentrations above 10 ppbv and 7% had benzene levels above 50 ppbv.

It was apparent that the data were not normally distributed. For usual inferential procedures of estimation and hypothesis testing to be valid, a normal distribution is necessary. In cases where the mean is positively correlated with the variance, as was the case with these indoor BETX measurements, a natural log transformation is often used so that assumptions regarding a normal distribution are more nearly met. This manipulation was used to successfully transform the data to a distribution that approximated normality. The transformed distribution is shown in Figure 3.

Subsequent statistical analysis was performed on this transformed data set. Summary statistics for the 137 indoor BETX measurements appear in Table 1. The geometric mean (exp (mean $\log_e$[BETX]) is reported along with the arithmetic mean. The geometric mean has the property of having units (i.e. ppbv) in common with other parametric statistics (e.g. arithmetic mean, median) while being mathematically related to the mean $\log_e$ concentration and the central tendency of the transformed data distribution. For this skewed data set, the geometric mean and arithmetic median were approximately the same. Multiple regression analysis was performed relating the dependent variable ($\log_e$ [BETX]) with survey data characterizing architectural, behavioral, and environmental factors in the homes sampled.

Summary of Outdoor BETX Measurements

An outdoor BETX measurement was paired with each indoor measurement. In most instances, a single outdoor sample served as the ambient or background VOC measurement for a group of three of four homes being sampled nearby. In all, 58 outdoor measurements were taken. These outdoor measurements are summarized in Table 2. The statistics compiled in this table were weighted in proportion to the number of indoor measurements with which they were paired.

Outdoor BETX concentrations were found to be five to ten times lower on average than those measured indoors.

Analysis of Architectural, Behavioral, and Environmental Factors Associated with Indoor Benzene - General Observations about the 137 Homes Sampled

Correlation matrices, stepwise multiple regression techniques and comparison of means were used to examine relationships between variables and assess their relative association with benzene levels. The SAS statistical package was used to identify collinear variables and sources of sampling bias.

A step-wise multiple regression model was developed to determine which variables had the greatest association with indoor benzene. To be included in the model, variables had to meet a 0.05 level of significance (p). This stepwise regression procedure was first run on the entire data set of 137 homes to identify the primary factors associated with elevated indoor benzene concentrations. The relative variance or partial r^2 in $\log_e$[benzene] explained by particular factors is depicted in Figure 4.

Five variables were found to be significantly associated with indoor benzene concentrations. Thirty-eight percent of the variance in $\log_e$[benzene] was explained by variables associated with the presence of an attached garage (i.e. trips by car in garage, forced air furnace in garage, fuel opened within 3 days). Twenty-two percent of the variance was explained by the ambient benzene concentration measured adjacent to the homes sampled and five percent was explained by the ambient temperature. Thirty-five percent of the variance was not explained by the regression model.

The regression model suggested that the presence of attached garages was a major influence on benzene concentrations in the 137 homes sampled. Much higher concentrations of benzene were observed in the group of homes with garages compared to the group without garages. Table 3 contains a summery of these data for the two groups.

Other VOCs were also higher in homes with attached garages. Table 4 compares BETX concentrations in homes with garages to those without. Geometric mean concentrations were two to four times higher in homes with attached garages.

The data were examined to determine whether other household characteristics, not necessarily associated with the presence of an attached garage, could account for the large observed differences in BETX concentrations between these two groups. Table 4 shows that ambient temperatures and outdoor benzene concentrations were comparable. The rate of tobacco use in the two groups was very nearly the same.

Analysis of Factors Influencing Benzene Concentrations in Homes With Attached Garages

It was apparent that the presence of an attached garage was the most important factor influencing benzene and other BETX concentrations in the 137 homes sampled. The geometric mean benzene concentration in homes with attached garages was four times higher than in those without a garage. Because of these large and obvious differences, it seemed likely that the architectural, behavioral and environmental factors influencing indoor BETX could be quite different in the two groups. For this reason, the sample of 137 homes was disaggregated into two sub-samples. One group contained the 91 homes with attached garages and the second group contained 46 homes without attached garages. This section discusses the factors influencing benzene concentrations in homes with attached garages.

A step-wise multiple regression model was used to identify factors associated with elevated indoor benzene in the 91 homes with attached garages. Figure 5 shows that the combined influence of ambient temperature and ambient benzene concentration accounted for approximately 27% of the variance observed in the $\log_e$[benzene]. It should be noted that these two variables were collinear and their influence on indoor benzene concentrations was difficult to distinguish (i.e. elevated ambient benzene concentrations were strongly associated with cold ambient temperatures). Thus, there was uncertainty about their relative influences. Both of these two factors may in fact be surrogates for a behavioral factor that was undocumented in the survey. The apparent link between elevated indoor benzene and cold temperatures may actually reflect the natural tendency of residents to shut doors and close windows during cold weather. It seems reasonable to assume that this practice would result in higher indoor benzene concentrations because ventilation with outside air is reduced, trapping VOC emissions inside the home. Thus, cold ambient temperatures and elevated ambient benzene could have been surrogates for limited air exchange in the home.

Indoor benzene increased in relation to the number of car trips originating from the attached garage. Approximately 13% of the total variance in $\log_e$[benzene] was explained by this behavioral factor. Another behavioral factor, whether fuel had been opened within the three days prior to the sampling period, accounted for 4% of the variance.

Particular architectural characteristics were also associated with indoor benzene. Indoor benzene levels were higher in homes with living space over the garage. This factor explained about 7% of the variance.

The type of heating system also seemed to influence indoor benzene. Eleven percent of the total variance was explained by this factor. Homes with forced air heat tended to have higher concentrations than those with hot water heating systems.

Approximately 62% of the variance in $\log_e$[benzene] was explained by the architectural, behavioral and environmental factors described above. Thirty-eight percent of the variance was unexplained by the regression model.

The general observations derived from the regression model results served as a starting point for further investigation. The mean $\log_e$[benzene] was compared for particular subsets within the group of homes with attached garages. This allowed the influence of specific architectural, behavioral and environmental factors to be more thoroughly evaluated.

A summary of some of the specific comparisons between subsets appears in Table 5. The results summarized in Table 5 are generally consistent with the expectation that elevated benzene concentrations would be associated with activities in an attached garage. Significantly higher benzene concentrations were found in homes where the garage was used to park at least one car. Higher benzene levels were also found in homes where fuel or solvents had been opened during sampling or in the three day period preceding sampling.

Although tobacco smoking has been observed to be a major source of indoor benzene in studies conducted elsewhere, it did not appear to be a significant influence in this group of homes. The contribution of tobacco smoke on indoor benzene may have been masked by other, more significant sources originating from the attached garage. The influence of tobacco smoking will be re-examined later in this report in the group of homes without attached garages.

The subset of large multifamily homes with vehicles in attached garages possessed some unique features that distinguished them from single family and small multifamily units. Garages in these buildings housed up to 50 vehicles. Numerous personal storage areas were also located in these garages, some of which undoubtedly were used to store fuel or small engines. The congregation of many vehicles and personal storage areas increased the likelihood of fuel leakage or spillage. Indeed, some leakage of fuel was observed in several of these attached garages. Some of the highest BETX concentrations observed in this study were measured in the living units above the garages where leakage was visible. Although benzene concentrations were higher on average in large multifamily units relative to single family and small multifamily units, the difference in the $\log_e$ [benzene] between groups was not statistically significant.

The type of heating system, forced air vs. hot water baseboard, also seemed to influence indoor benzene levels. In homes with one or more cars parked in the garage, the geometric mean benzene concentration was two times higher in homes with forced air heating systems than in homes with hot water heat.

The configuration of the living space in the home in relation to the garage was sometimes significantly associated with $\log_e$[benzene]. Indoor benzene concentrations were particularly high in homes with forced air heat and living space configured over the garage. These homes had a geometric mean benzene concentration several times higher than homes without a room over the garage. In homes with forced air systems, temporary localized pressure imbalances occur during a heating cycle as air is circulated by fans. It is possible that benzene from the garage could be drawn into the living area of the home by a negative pressure differential developed during these heating cycles. This phenomena may be enhanced in homes with rooms located directly above the garage. Further study is necessary to evaluate this hypothesis. In homes with hot water baseboard systems, the living space configuration was not as strongly correlated with indoor benzene.

Analysis of Factors Influencing Benzene Concentrations in Homes Without Attached Garages

Homes with attached garages were discussed in the previous section. A similar analysis was performed on the group of 46 homes without attached garages. The geometric mean benzene concentration was about four times lower in these homes. Most of the homes without attached garages had indoor benzene levels at or slightly above outdoor background levels, suggesting that indoor sources of benzene were often negligible. In this group of homes the impact of more subtle influences on indoor benzene were revealed when the apparent overwhelming influence of factors related to attached garages was eliminated.

A step-wise regression model was developed to identify the architectural, behavioral and environmental factors associated with $\log_e$[benzene] in homes without attached garages. The results of this analysis are summarized in Figure 6.

Environmental factors appeared to play a more influential role in homes without attached garages. Thirty percent of the variance in $\log_e$[benzene] was attributed to ambient temperature. The ambient benzene concentration measured adjacent to the home accounted for about 12% of the variance. Together, these two environmental factors explained 42% of the variance. In contrast, these same two factors explained only 27% of the variance in the group of homes with attached garages. Again, it should be noted that ambient temperature and ambient benzene are collinear and their influences on indoor benzene is difficult to separate. As was explained in the earlier section, both of these factors could be surrogates for lower outside air infiltration rates.

Though the multiple regression attributes 13% of the variance in $\log_e$ [benzene] to the opening of solvents or fuel within the home, this occurred in only 2 of the 46 homes sampled. In these two homes, the geometric mean benzene concentration was six times higher than in homes where fuel was not opened. Although this difference was statistically significant (p=0.003), it should be noted that the sample size for the group who opened fuel was very small.

Table 6 indicates that benzene concentrations were higher in homes where tobacco smoking occurred. The geometric mean benzene concentration was about twice as high in homes where there was smoking (2.9 ppbv vs. 1.4 ppbv). This difference approached statistical significance (p=0.06). Sample size was relatively small, however. Only seven of the 46 homes housed smokers. Although this difference in the $\log_e$ benzene concentration between smoking and non-smoking households fell short of meeting the level of significance criteria, it was consistent with the findings of other studies. The TEAM study conducted by Wallace in 1987 concluded that households with smokers were likely to have benzene levels in indoor air that were 50% greater on the average than homes without smokers. A German study of 488 homes (5) corroborated these findings.

CONCLUSIONS

The major findings of this study are summarized below:

1. The levels of indoor benzene and other VOC’s varied widely in the 137 Anchorage homes sampled in this study. Most of the homes sampled had benzene concentrations below 5 ppbv. One-fourth of the homes sampled had benzene concentrations above 10 ppbv. In these homes benzene concentrations were about an order of magnitude higher than concentrations measured outdoors. This suggests that indoor sources are primarily responsible when elevated levels of benzene and other VOCs are observed in Anchorage homes.

2. Homes with attached garages had significantly higher levels of benzene and other VOCs than homes without attached garages. Geometric mean benzene concentrations were four times higher in homes with attached garages than in homes without attached garages. No other architectural, behavioral or environmental factor was as strongly associated with elevated benzene and other VOCs as the presence of an attached garage.
3. In dwellings with an attached garage, benzene and other VOCs were significantly higher if the garage was used to park a car. Geometric mean benzene levels were almost five times higher in these homes.
4. Among homes with attached garages, higher indoor benzene levels were observed when the garage was used to store fuel or small engines. Elevated benzene levels were also correlated to recent opening of fuel or solvents.
5. Homes with living space located directly above the garage had significantly higher indoor benzene concentrations than those homes where the attached garage was located adjacent to the living space of the home.
6. Among homes with attached garages, those with forced air heating systems had significantly higher levels of benzene and other VOCs than those with hot water heat. Localized pressure imbalances from air handling during the forced air heating cycle may facilitate air infiltration into the home from the garage where fuel vapors may be present.
7. The relatively high benzene content and volatility of Alaskan gasoline may increase benzene emissions from cars, small engines and fuel storage containers in attached garages. Although the effects of the high volatility and benzene content of Alaskan fuel were not investigated in this study, other studies suggest a relationship between gasoline benzene content and ambient concentrations (6).
8. In contrast with a number of studies conducted elsewhere, tobacco smoking was not strongly associated with elevated indoor benzene in Anchorage homes. Its influence may have been overwhelmed by more significant sources associated with the attached garage.
   In homes without an attached garage, however, benzene concentrations were about twice as high in homes where tobacco smoking occurred. This was consistent with the findings of other studies.

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Table 1. Summary statistics: Indoor BETX concentrations in 137 Anchorage homes (all values ppbv)

	benzene	**toluene**	**ethylbenzene**	**m&p-xylene**	**o-xylene**
arithmetic mean	15.8	39.3	6.7	21.3	7.6
geometric mean	4.1	13.1	1.6	5.5	3.0
maximum	364	1033	259	793	152

Table 2 Summary statistics: Outdoor BETX concentrations measured near the 137 Anchorage homes sampled (all values ppbv)

	benzene	**toluene**	**ethylbenzene**	**m&p-xylene**	**o-xylene**
arithmetic mean	1.9	4.3	0.8	1.8	1.4
geometric mean	1.3	2.5	0.4	1.2	1.0
maximum	13.3	31.5	15.9	14.3	5.3

Table 3. Comparison of benzene concentrations in homes with attached garages vs. homes without attached garages.

	n	**minimum (ppbv)**	**maximum (ppbv)**	**arithmetic mean (ppbv)**	**geometric mean (ppbv)**
attached garages	91	0.2	364	22.2	6.6
no garage attached	46	0.3	17.9	2.7	1.6

The difference in log mean concentration between groups was highly significant ($p=0.0000002$)

Table 4. Comparison of BETX concentrations and selected household characteristics between homes with and without attached garages.

	Homes without attached garages (ppbv)				**Homes with attached garages (ppbv)**			
	min	max	arithmetic mean	geometric mean	min	max	arithmetic mean	geometric mean
benzene	0.3	17.9	2.7	1.5	0.2	364	22.4	6.6
toluene	1.3	246	18.0	8.1	0.2	1033	50.0	16.9
ethylbenzene	0.1	13.8	1.7	0.8	ND	259	9.2	2.3
m/p-xylene	0.4	47.2	5.3	2.7	0.1	793	29.4	7.9
o-xylene	0.2	24.4	3.4	1.9	0.1	152	9.7	3.7
number homes sampled	46				91			
average year built	1970				1976			
% homes fuel opened within 3 days of sampling	4%				11%			
fuel or small engines stored in garage	N/A				57%			
% of homes with tobacco smoking	15%				14%			
% homes with interior painting within last 2 weeks	6%				13%			
<u>type of heating system</u>								
hot water	65%				62%			
forced air	26%				36%			
electric	9%				2%			
ambient temperature (arithmetic mean)	40 °F				35 °F			
outdoor or “background” benzene concentration (arithmetic mean)	1.5 ppbv				1.8 ppbv			

Table 5. Analysis of factors influencing benzene concentrations in homes with attached garages: comparisons of mean ($\log_e$ [benzene])

Subsets compared/ Correlation	level of significance (p)	Comments
All homes with attached garages (n=91)		
Homes with attached garages: those with parked vehicles (n=69) vs. those without (n=23).	0.00006	Mean $\log_e$[benzene] was significantly higher in homes where car is parked in garage compared to homes where car is not parked in garage (geometric mean 9.6 vs. 2.0 ppbv).
Homes with attached garages: those who had opened fuel (n=10) vs. those who had not (n=81).	0.004	Mean $\log_e$[benzene] is significantly higher where fuel was opened in last 3 days (geometric mean when fuel opened = 26.0 ppbv, no fuel opened = 5.6 ppbv)
Homes with attached garages: those who had smoked tobacco (n=13) vs. those who had not (n=78).	0.80	There was no significant difference in the mean $\log_e$[benzene] between homes with at least one smoker vs. those with nonsmokers (geometric mean: homes with smokers = 6.0 ppbv, homes with no smokers = 6.7 ppbv)
Homes with attached garages: large multifamily units (n= 13) vs. single family and small multifamily units (n=78).	0.11	Large multifamily units tended to have higher indoor benzene levels than single family and small multifamily units (geometric mean 12.9 vs. 5.9 ppbv). However, this difference in $\log_e$ [benzene] was not statistically significant.
Homes with attached garages and at least one vehicle parked inside (n=67)		
Homes with vehicles in attached garages: those where no trips were taken (n=12) vs. those who had taken at least one trip during sample period (n=46).	0.65	No significant difference between groups. Spilled fuel was observed in some garages where no trips had been taken.
Homes with vehicles in attached garages: those with forced air furnaces (n= 26) vs. those with hot water boilers (n= 41).	0.02	For the group of homes with cars parked in attached garages, $\log_e$[benzene] was significantly higher for those heated by forced air compared with hot water systems (geometric mean 16.3 vs. 6.9 ppbv).
Various housing and heating system configurations (n varies)		
Homes without vehicles parked in the attached garage, all heating systems: homes with living area above garage (n=7) vs. homes without (n= 15)	0.04	Homes with some living area above garage had significantly higher $\log_e$[benzene] than those with an attached garage configured adjacent to living area (geometric mean 5.1 vs. 1.3 ppbv), even when no car was parked in garage.
Homes with vehicles parked in the attached garage and a forced air heating system: those with living area above garage (n=14) vs. those without (n= 12)	0.001	For homes with a forced air heating system and cars parked in the garage, those with some living area above garage had significantly higher $\log_e$[benzene] than those with an attached garage configured adjacent to living area (geometric mean 36.2 vs. 6.4 ppbv).
Homes with vehicles in attached garages and hot water heat: those with living area over garages (n=19) vs. those without (n=22).	0.23	For homes with a hot water heating system and cars parked in the garage, those with living area over the garage had higher $\log_e$[benzene] than those with an attached garage configured adjacent to living area (geometric mean = 9.4 vs. 5.4 ppbv). This difference was not statistically significant.

Table 6. Factors influencing benzene concentrations in homes without attached garages: Comparison of means ($\log_e$ [benzene])

Groups compared/ Correlation	p value	Comments
Homes without attached garages: those who had opened fuel or solvents (n=2) vs. those who had not (n=44)	0.0003	Mean $\log_e$ [benzene] is significantly higher when fuel was opened in last 3 days (geometric mean when fuel opened = 8.6 ppbv, no fuel opened = 1.4 ppbv)
Homes without attached garages: those who had smoked tobacco (n=7) vs. those who had not (n=39)	0.06	Benzene concentrations were higher in homes with at least one person who smoked than in those without a smoker (geometric mean 2.9 ppbv vs. 1.4 ppbv). However, this did not meet the established level of significance criteria (p=0.05).
Homes without attached garages: those who had painted the interior of their homes within 2 weeks (n=3) vs. those who had not (n=43)	0.09	Benzene concentrations were slightly higher for the few who had painted vs. those who had not (geometric mean 1.6 ppbv vs. 1.2 ppbv). This difference was not statistically significant.

Figure 1. Dwelling unit type: Sample distribution vs. actual Anchorage housing stock

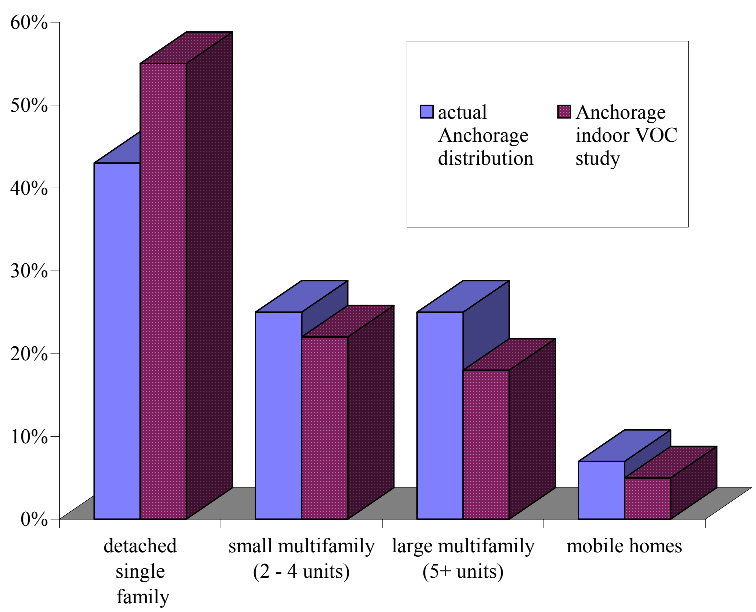

Figure 2. Frequency distribution of benzene concentrations measured in Anchorage homes.

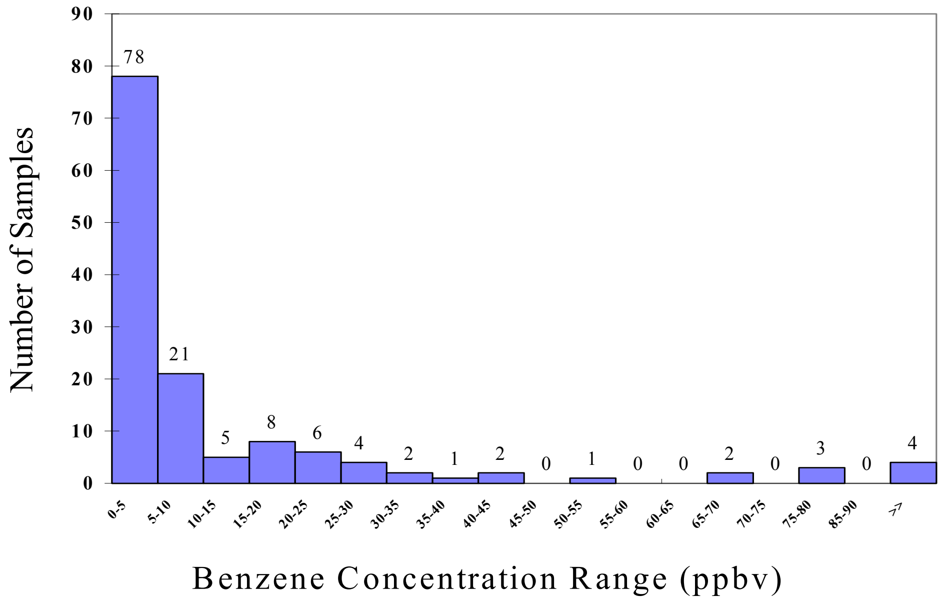

Figure 3. Frequency distribution of $\log_e$ transformed benzene concentration.

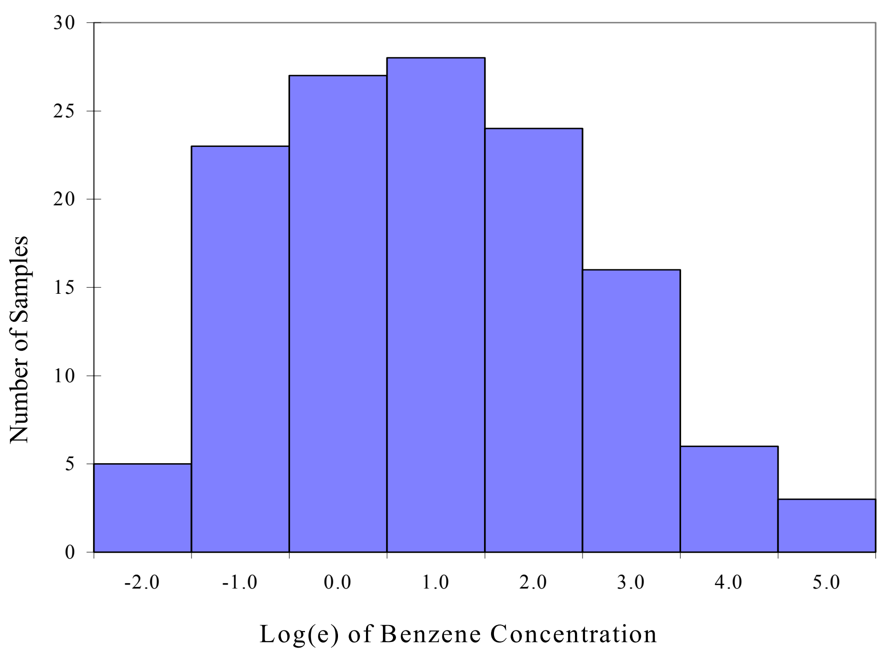

Figure 4. Architectural, behavioral and environmental variables associated with indoor benzene in 137 Anchorage homes (% variance in loge [benzene] explained).

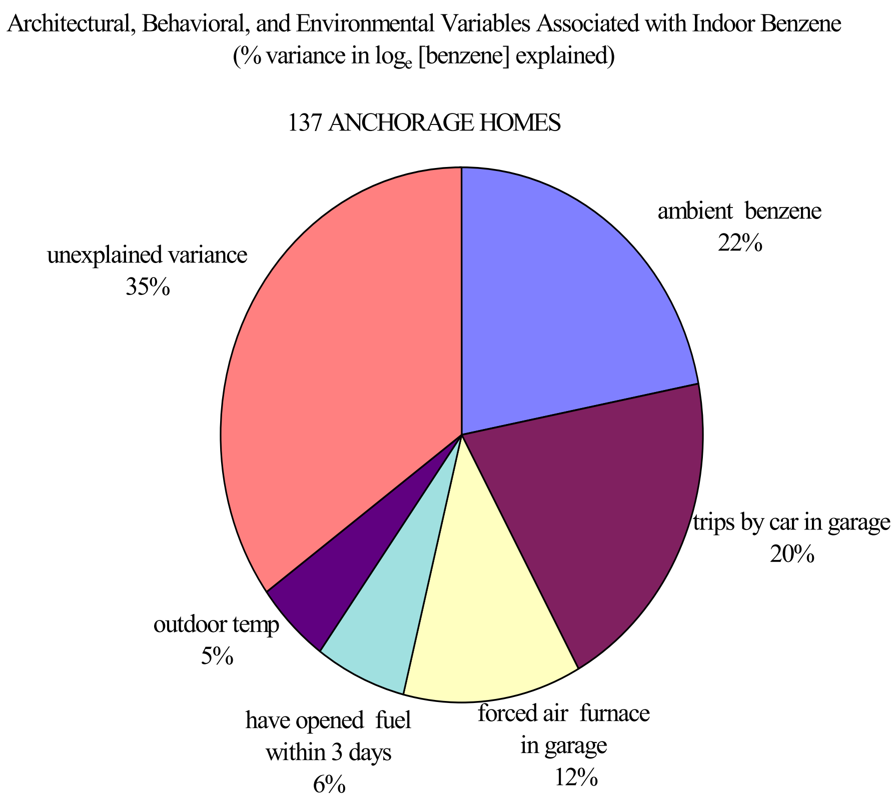

Figure 5. Architectural, behavioral and environmental variables associated with indoor benzene in 91 Anchorage homes with attached garages (% variance in loge [benzene] explained).

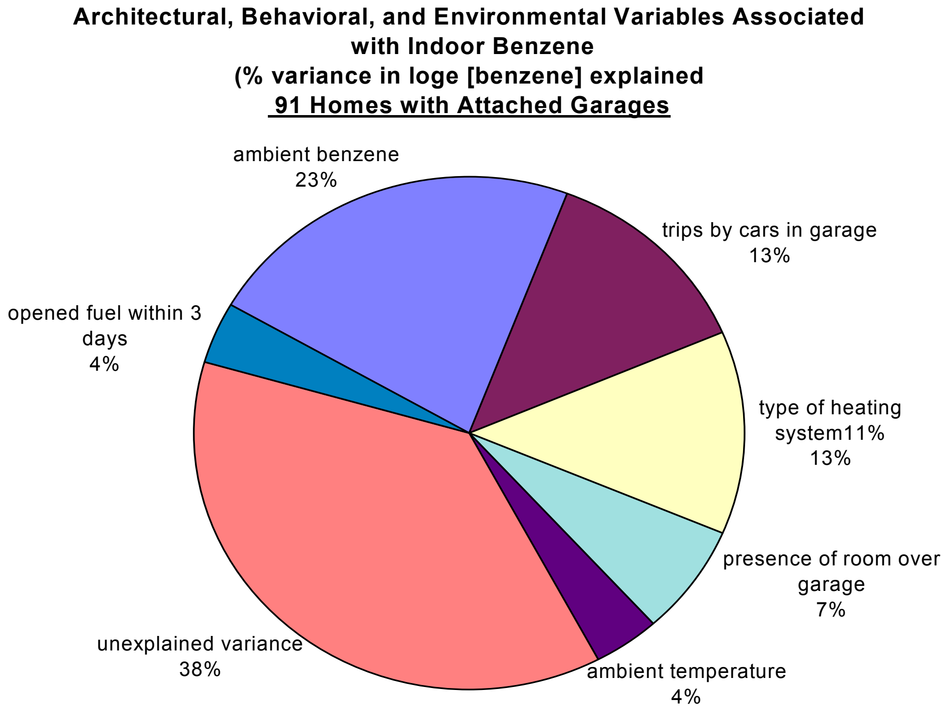

Figure 6. Architectural, behavioral and environmental variables associated with indoor benzene in 46 Anchorage homes without attached garages (% variance in loge [benzene] explained).