

Influence of Attached Garages on Indoor VOC Concentrations in Anchorage Homes

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Background

**A previous Anchorage study
sparked interest in a further
investigation into the influence of
attached garages on air quality
inside Anchorage homes.**

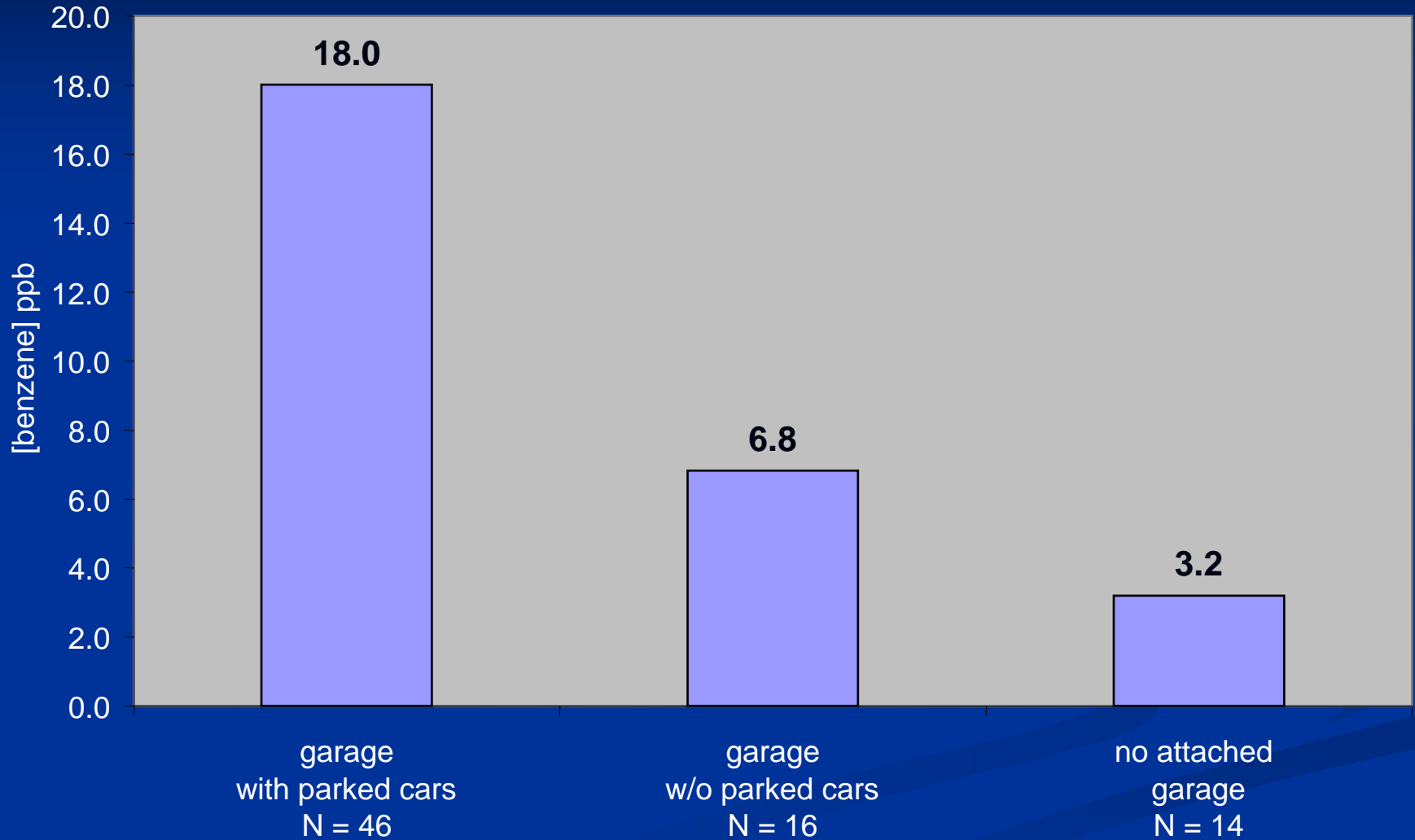
Architectural, Behavioral, and Environmental Factors Associated with Indoor VOCs in Anchorage Homes (1995)

- Sampled 137 homes for BETX between December 1994 and February 1996
- Summa canisters deployed in living space of homes for 24 hours
- Documented architectural, behavioral and environmental characteristics of each home sampled

The most important factor influencing [benzene] and other BTEX compounds was the presence of an attached garage.

- Cigarette smoking was not an important factor in determining benzene concentration in living space of the home.
- The presence of an attached garage was the single most important variable associated with elevated benzene inside the home.

Comparison of Mean Benzene Concentrations in Single Family Homes 1994-1996 Anchorage Study



**Data suggested that
attached garages increase
in-home exposure to benzene
five-fold.**

**Incremental increase in lifetime
exposure cancer risk was
approximately
1 in 6,000.**

Benzene content (3.9%) and volatility of Alaska gasoline is higher than most of the U.S.



We wanted to explore the mechanisms responsible for elevated benzene in homes with attached garages.

Study Objectives

- Measure VOC concentrations in a representative sample of 50 Anchorage homes with attached garages to assess personal exposures.
- Measure garage to house air infiltration rates. Determine architectural / mechanical factors affecting the amount of air entering house from the garage.
- Identify possible strategies for reducing in-home VOC exposures through modification of architectural features, mechanical systems and/or modification of personal behaviors.

- How much garage air infiltrates into the home and what are the responsible mechanisms?
- How high are benzene and other VOCs inside the garage and what sources are responsible?

We narrowed study scope to include non-smoking, detached single family homes with attached garages only.

- Simplified analysis of air exchange rates.
- Eliminated other possible confounding variables.
- Confined sampling to winter season when previous study showed VOC concentrations were highest.

House selection



A representative sample of Anchorage homes was selected for sampling.

- Used Anchorage municipal property tax database to characterize housing stock by age and square footage.
- Selected proportional number of houses in each sampling bin.

Age and size distribution of detached single family homes with attached garages in Anchorage.

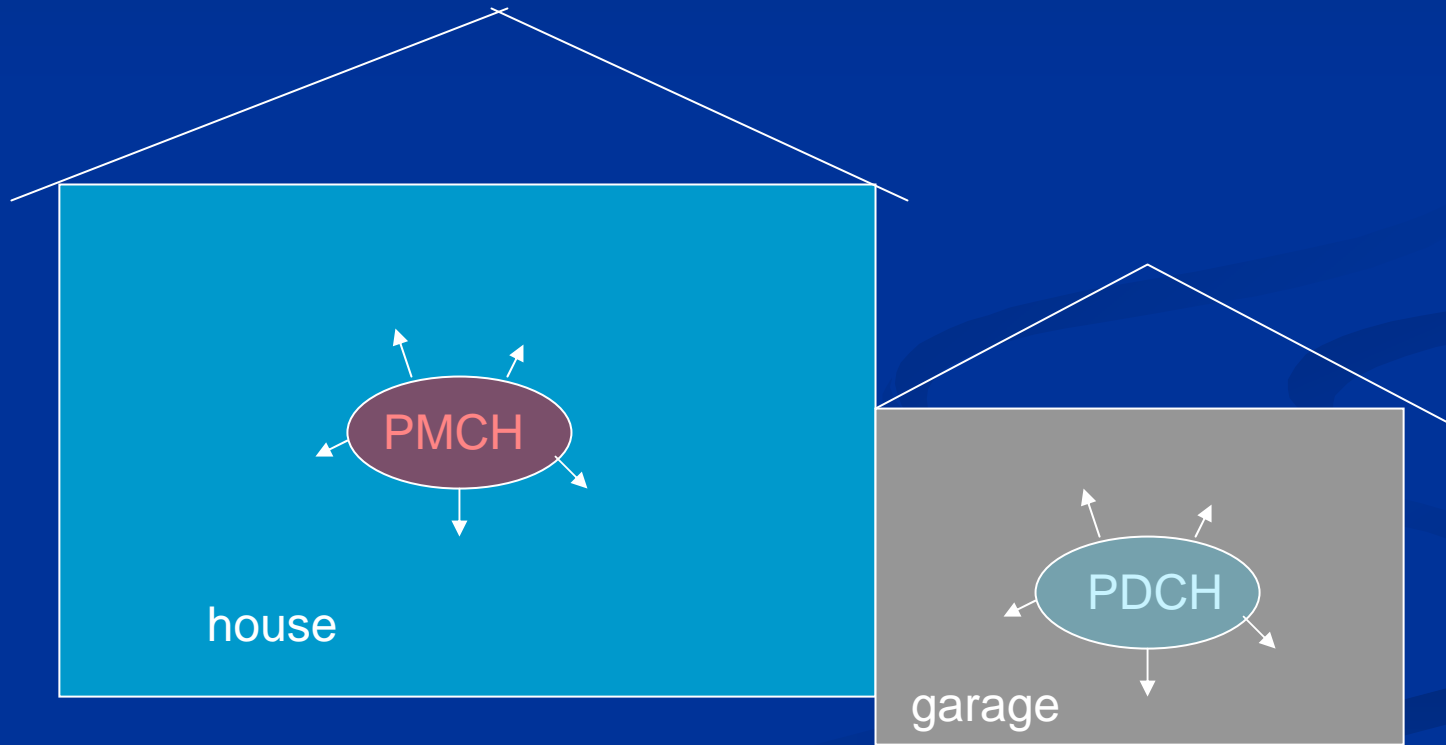
	<i>Pre 1960</i>	<i>1960-1969</i>	<i>1970-1979</i>	<i>1980-1989</i>	<i>1990-2003</i>	<i>Grand Total</i>
<i>Less Than 1,200 SF</i>	1.71%	1.52%	1.61%	1.99%	0.30%	7.13%
<i>1200-1799 SF</i>	1.28%	2.70%	6.60%	9.62%	6.81%	27.02%
<i>1,800-2,499 SF</i>	1.06%	4.98%	15.55%	10.00%	12.27%	43.86%
<i>2,500-4,999 SF</i>	0.73%	2.06%	6.07%	5.67%	6.51%	21.03%
<i>5,000 & Greater SF</i>	0.02%	0.04%	0.19%	0.27%	0.43%	0.96%
<i>Grand Total</i>	4.80%	11.30%	30.02%	27.56%	26.32%	100.00%

Resultant sampling profile (50 home target)

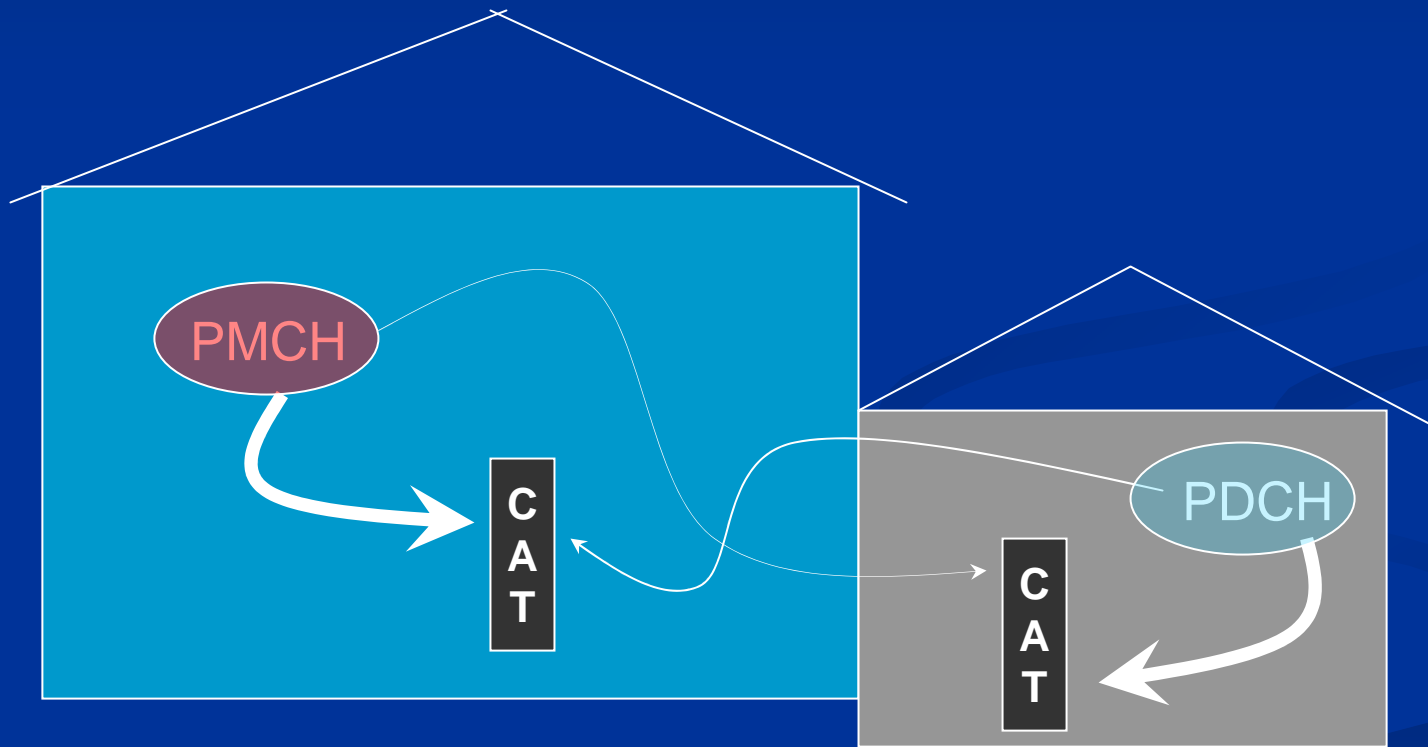
	<i>Pre 1960</i>	<i>1960-1969</i>	<i>1970-1979</i>	<i>1980-1989</i>	<i>1990-2003</i>	<i>Grand Total</i>
<i>Less Than 1,200 SF</i>	1	1	1	1	0	4
<i>1200-1799 SF</i>	1	1	3	5	3	14
<i>1,800-2,499 SF</i>	1	2	8	5	6	22
<i>2,500-4,999 SF</i>	0	1	3	3	3	11
<i>5,000 & Greater SF</i>	0	0	0	0	0	0
<i>Grand Total</i>	2	6	15	14	13	50

Tracer gases were used to estimate air exchange rates between garage and house.

A PMCH tracer gas source emitter was deployed in each house and a PDCH source in each garage. The emission rate of each source was known.

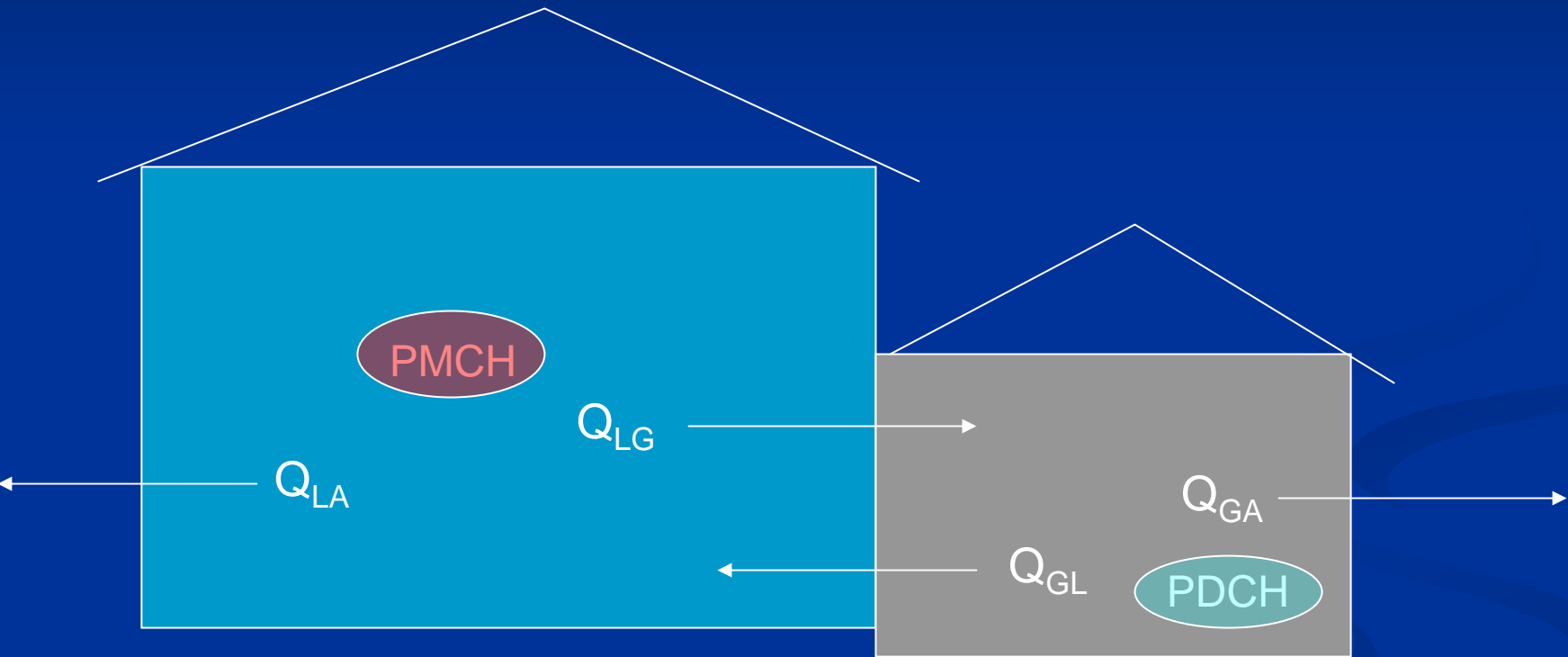


Capillary absorption tubes (CATs) were deployed in the house and garage to measure concentrations of PMCH and PDCH over a 24-hour period.



Mass balance approach was used to compute air exchange rates between garage and house, house and outside, and garage and outside.

Four simultaneous equations were developed to estimate 4 unknown flows from measured [PMCH] and [PDCH] and the known emission rates of the two tracer gases.

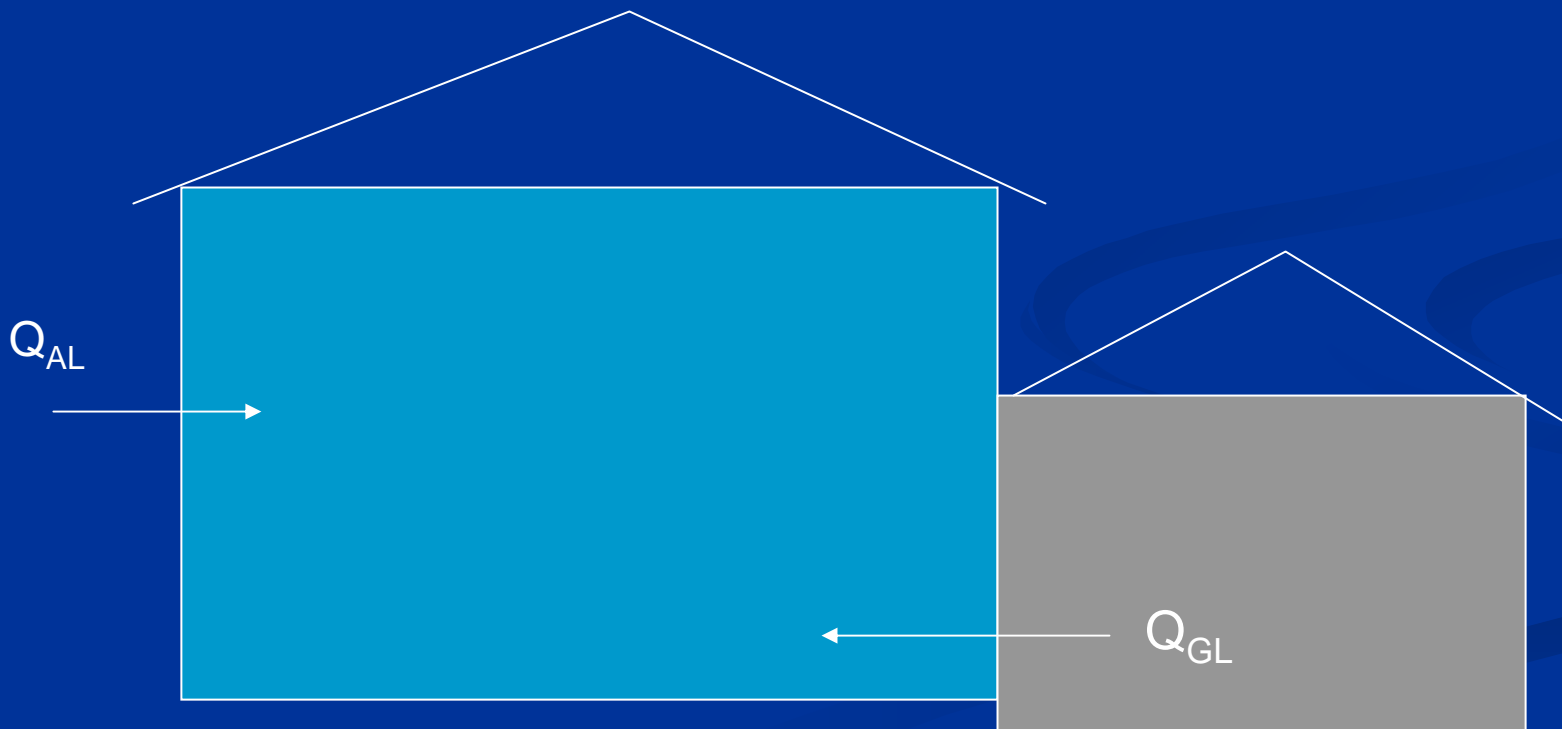


Simultaneous equations could be solved and flow rates Q_{GL} , Q_{GA} , Q_{LG} , and Q_{LA} could be computed for each house.

The proportion of air in the house coming from the garage could be easily derived.

Proportion of house air coming from garage =

$$Q_{GL}/(Q_{GL} + Q_{AL})$$



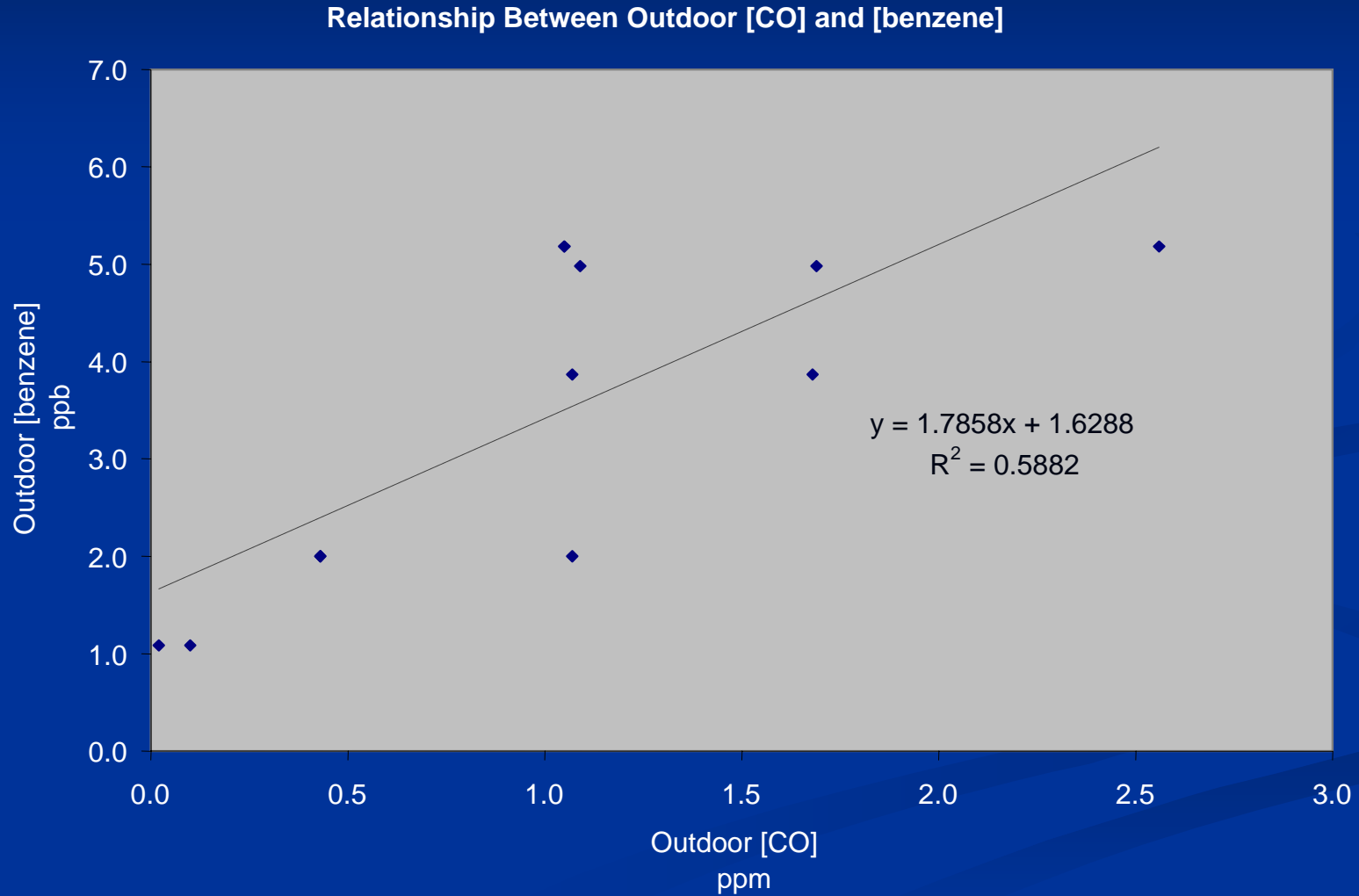
VOC sampling methodology

- ATD tubes were used to collect VOC samples in the house and garage.
- Samplers were deployed in active living space in home, typically in living room.





Ambient CO measurements were used to estimate outdoor concentrations of BTEX and butadiene.

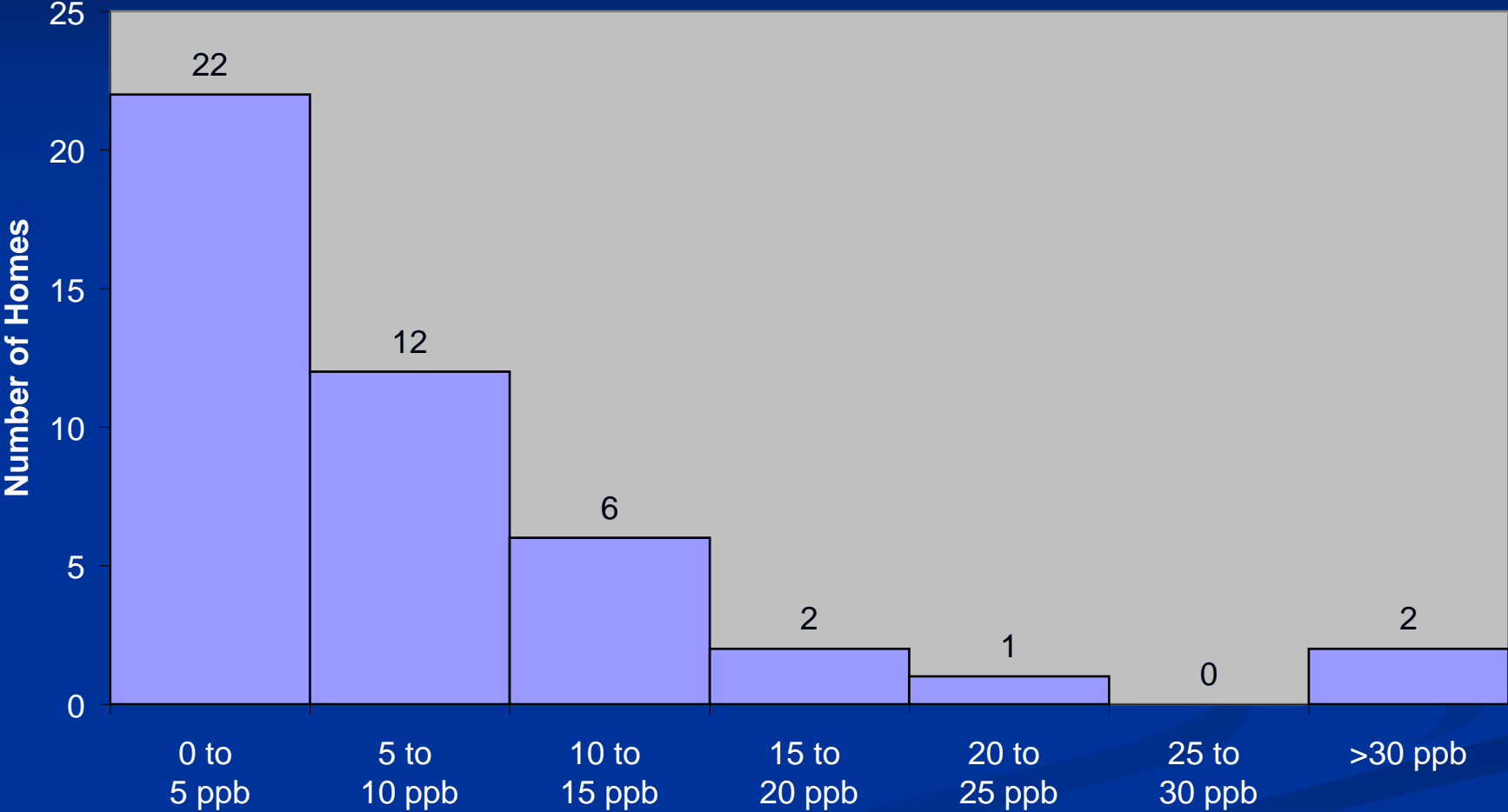


VOC results

Summary of In-house VOC Concentrations

	N	mean	median	max
1,3-butadiene	46	0.73	0.44	6.26
benzene	45	7.60	5.16	35.49
carbon tetrachloride	46	0.08	0.09	0.13
chlorobenzene	46	0.14	0.09	0.62
ethylbenzene	46	2.51	1.65	9.34
methylene chloride	46	2.79	0.35	73.16
naphthalene	46	0.14	0.08	1.20
o-xylene	46	2.98	2.15	11.21
toluene	46	18.89	12.91	81.73
trichloroethene	44	0.03	0.02	0.49
m,p-xylene	46	6.92	5.19	33.78

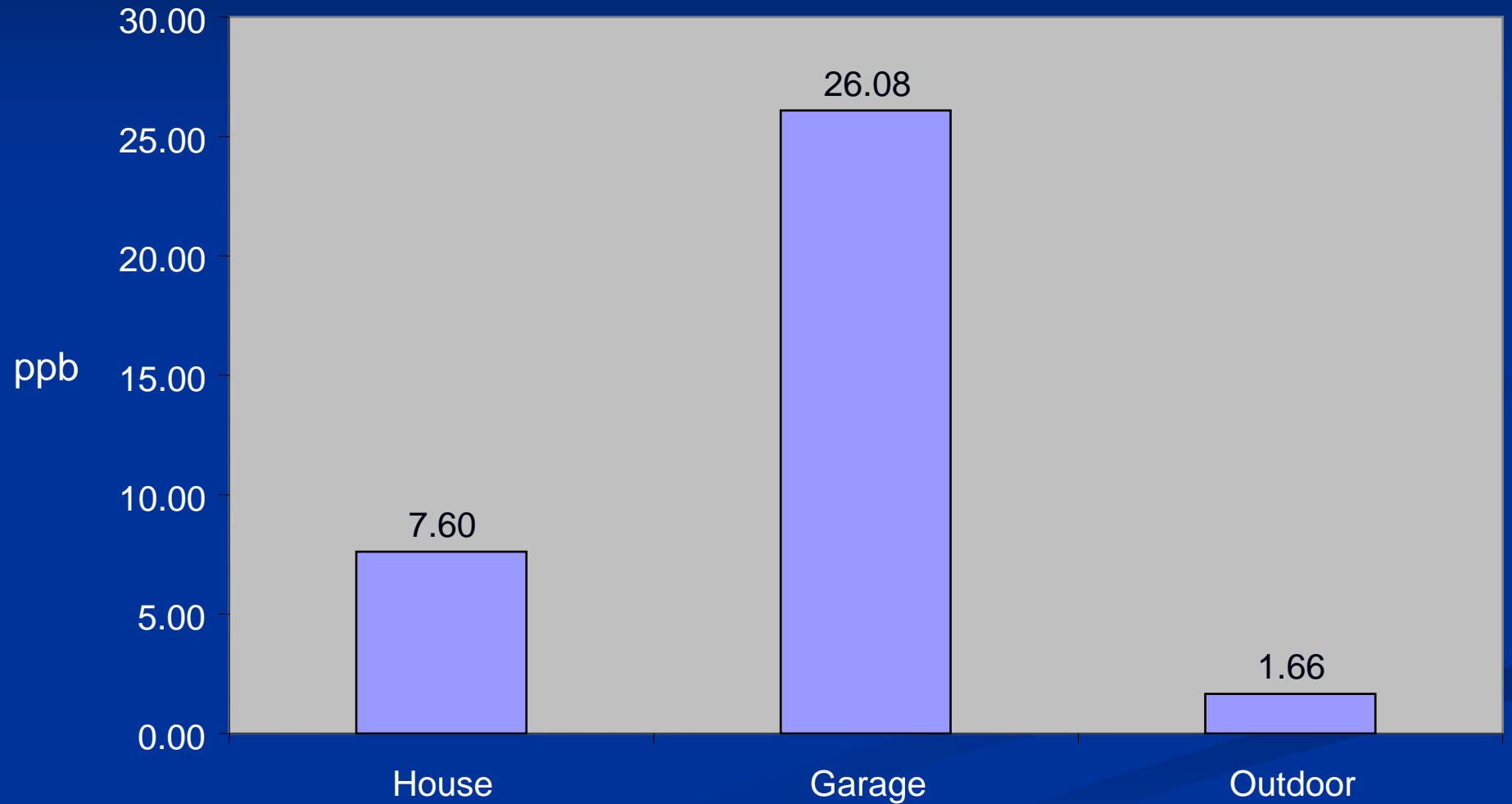
Distribution of Benzene Concentrations Inside Homes with Attached Garages



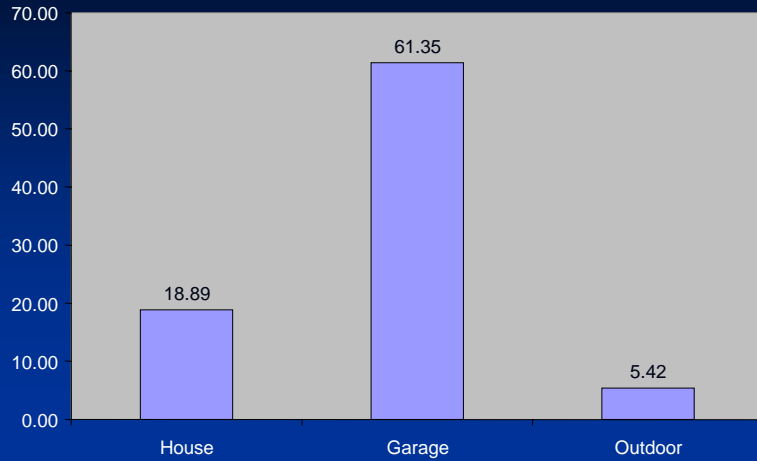
For benzene and other BTEX compounds, mean concentrations in the house were approximately 5 times higher than outside.

Garage concentrations were 10 to 15 times higher than outside.

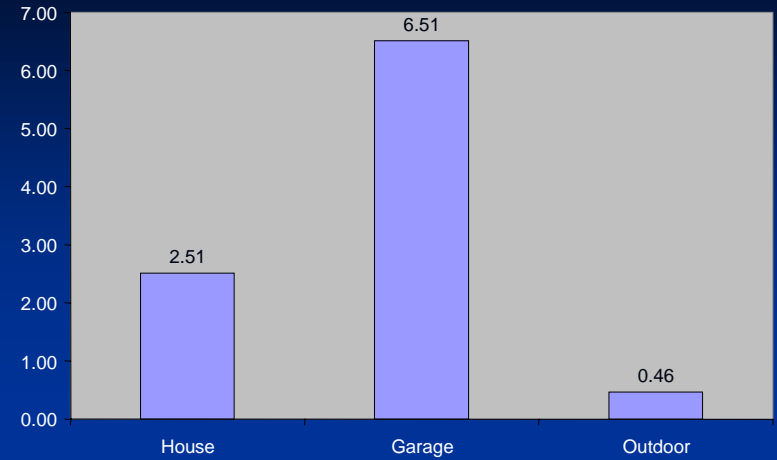
Mean Benzene



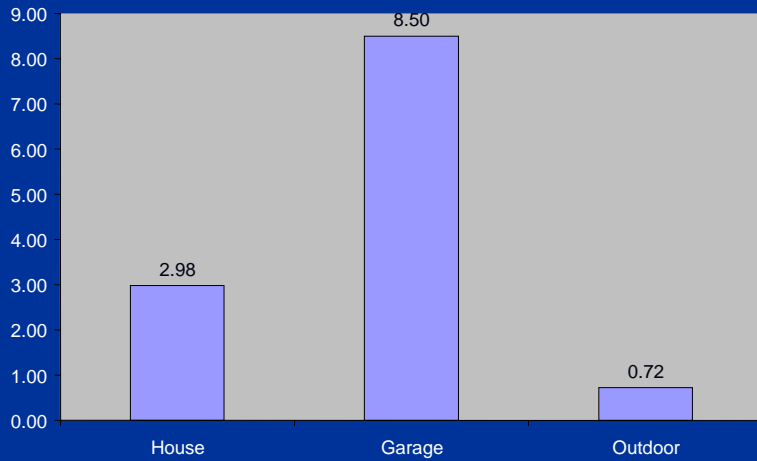
Toluene



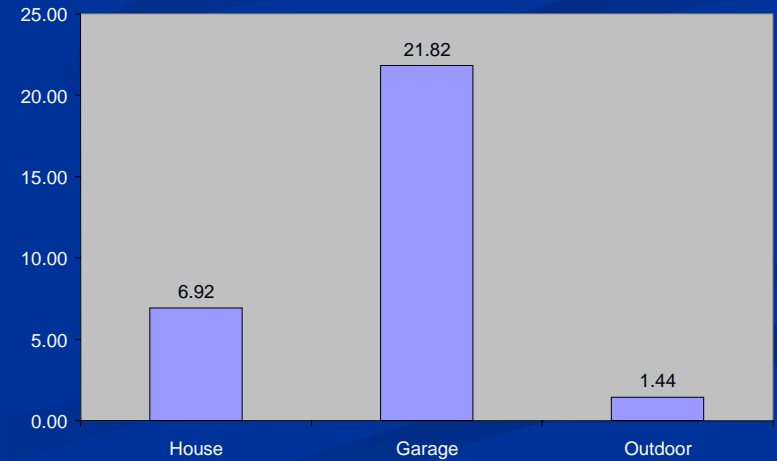
Ethylbenzene



o-Xylene



m,p-Xylene



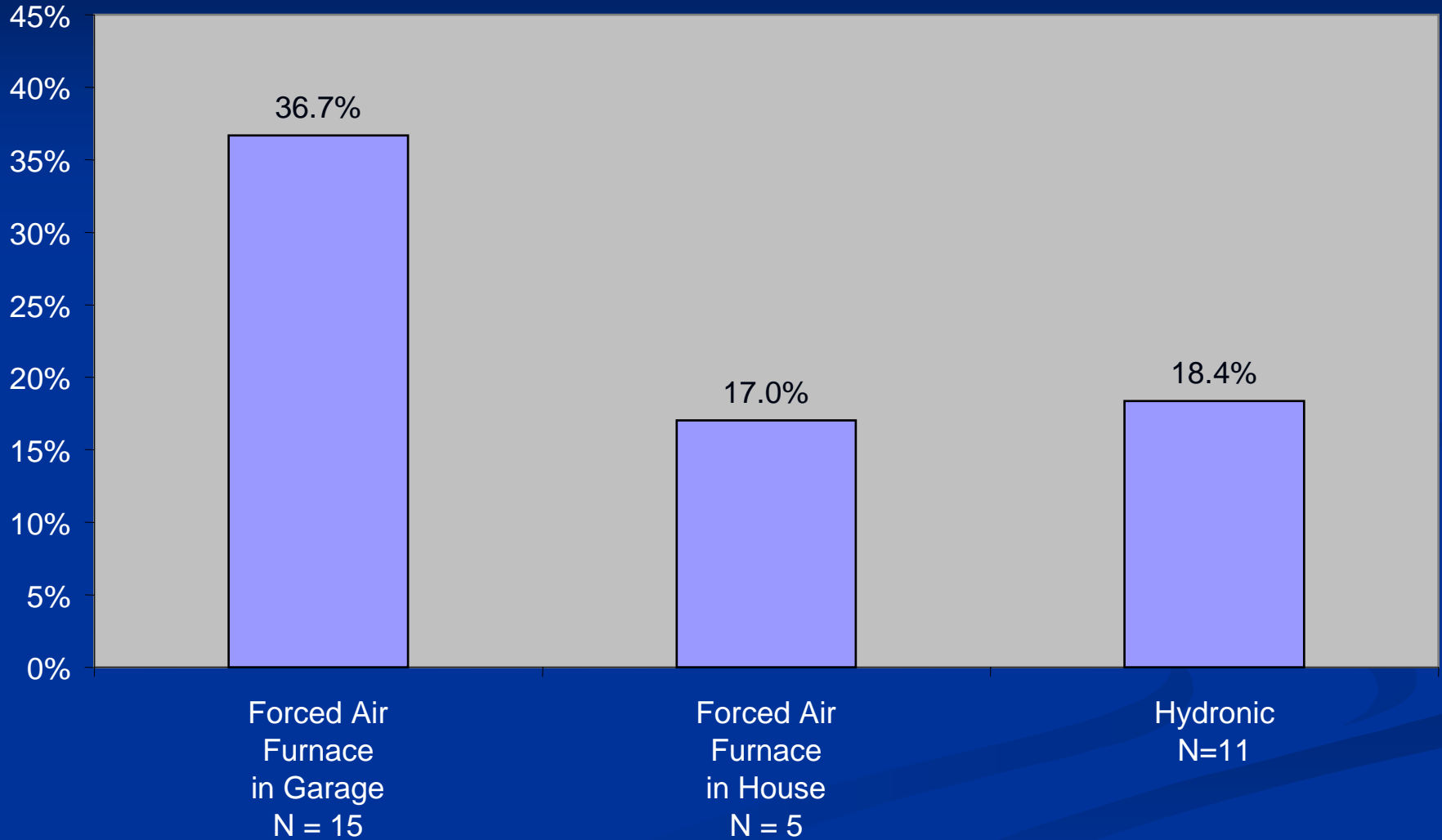
Data Analysis and Discussion

Garage to house infiltration rates varied considerably among homes sampled.

Homes with forced air furnaces in the garage had higher infiltration rates than homes with other heating configurations.

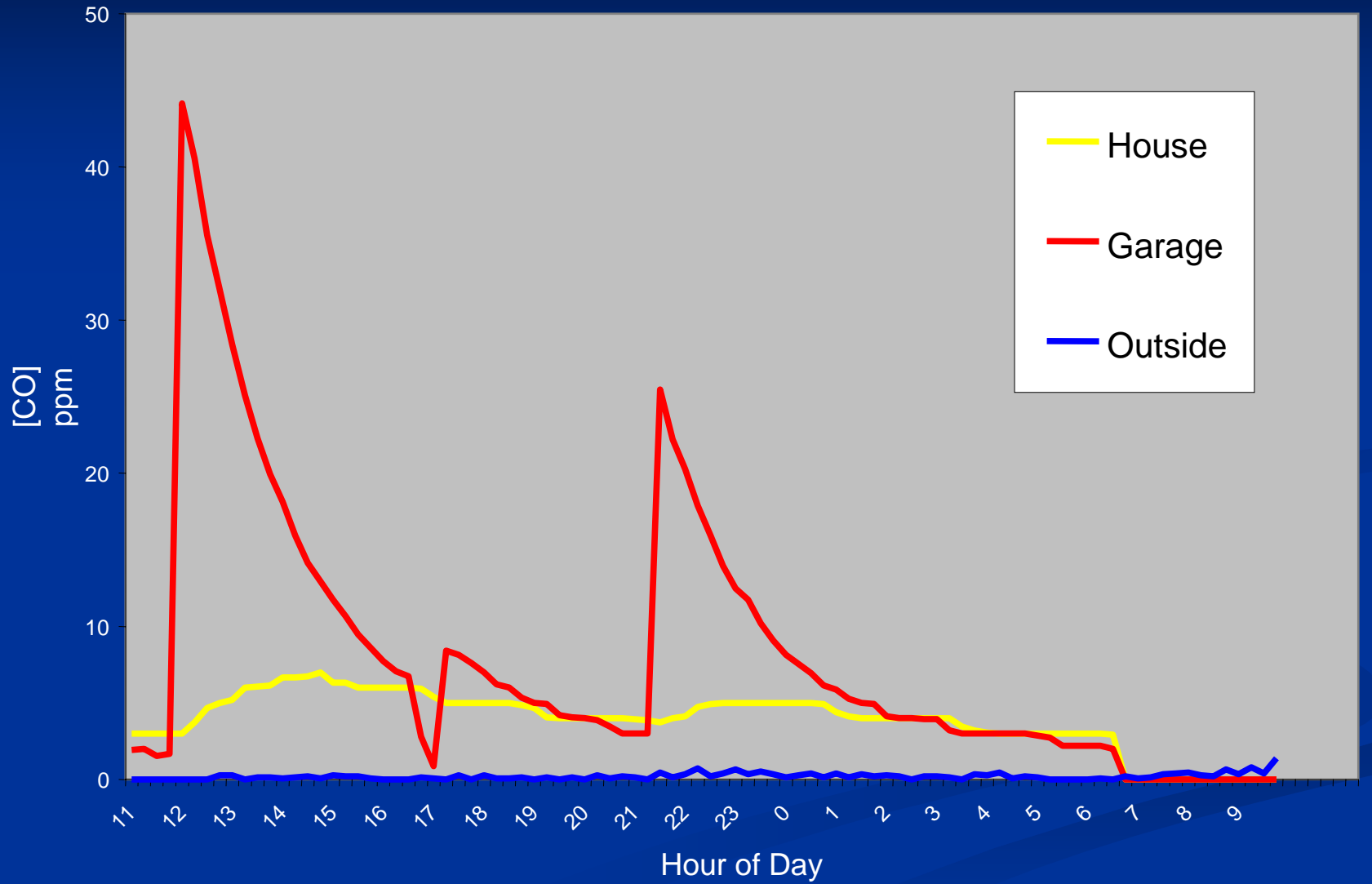


Comparison of Median Infiltration Rates Proportion of House Air Originating from Garage

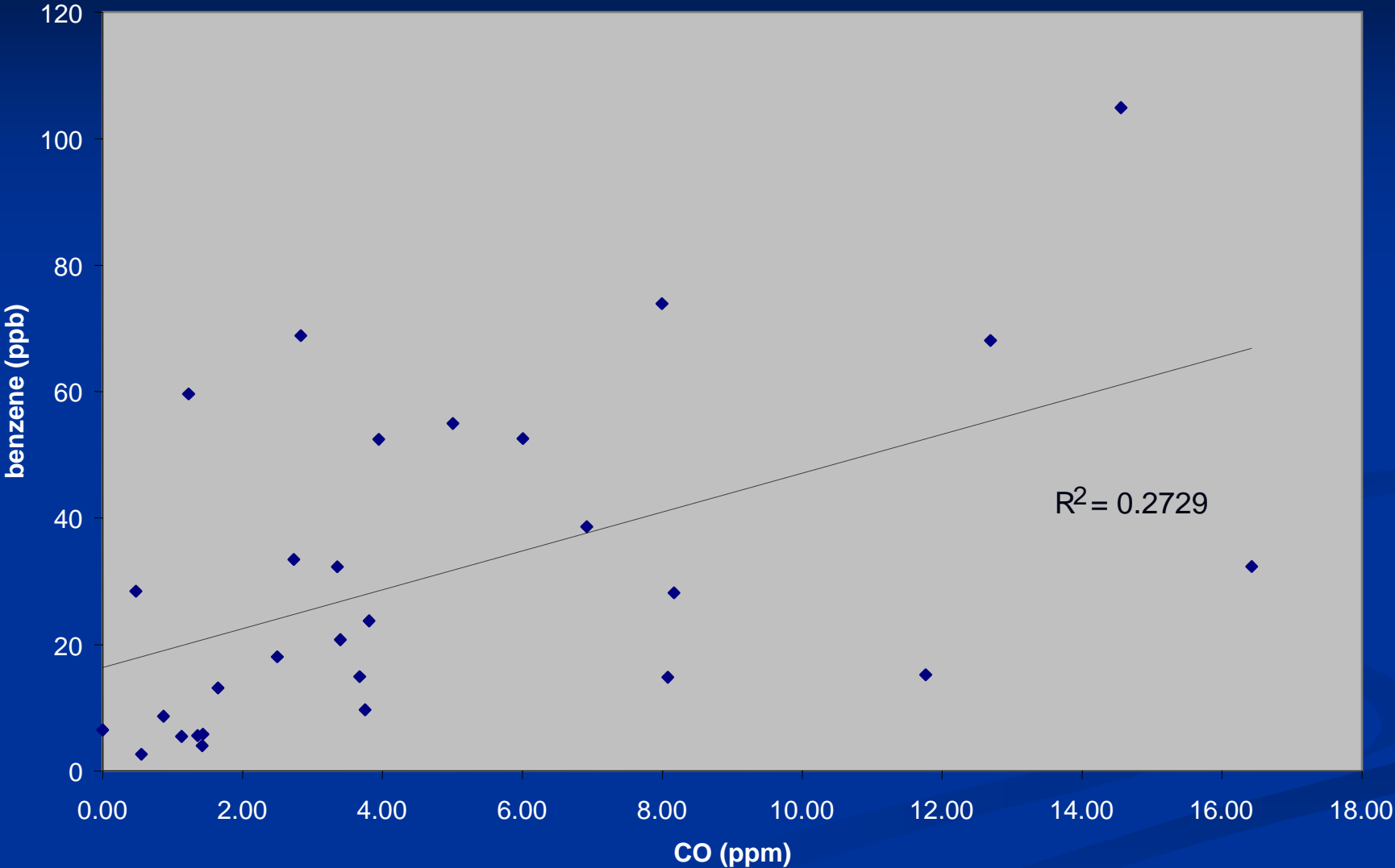


Although the [CO] in many garages was high immediately after vehicle start-ups, exhaust emissions do not appear to be the primary source of VOCs in the garage.

House 30

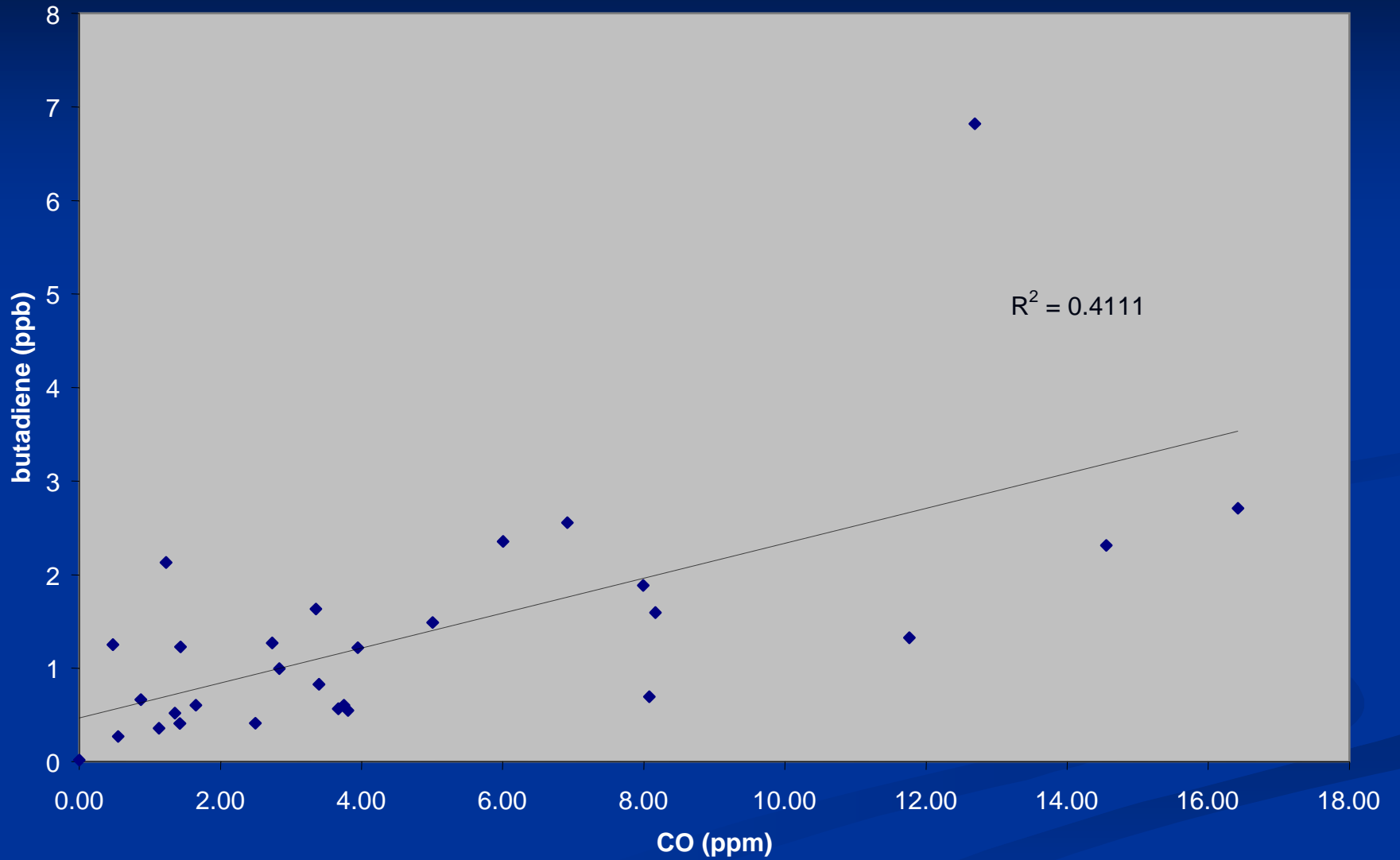


CO vs benzene in garage



**There was a stronger relationship
between CO and butadiene
concentrations.**

CO vs butadiene in garage



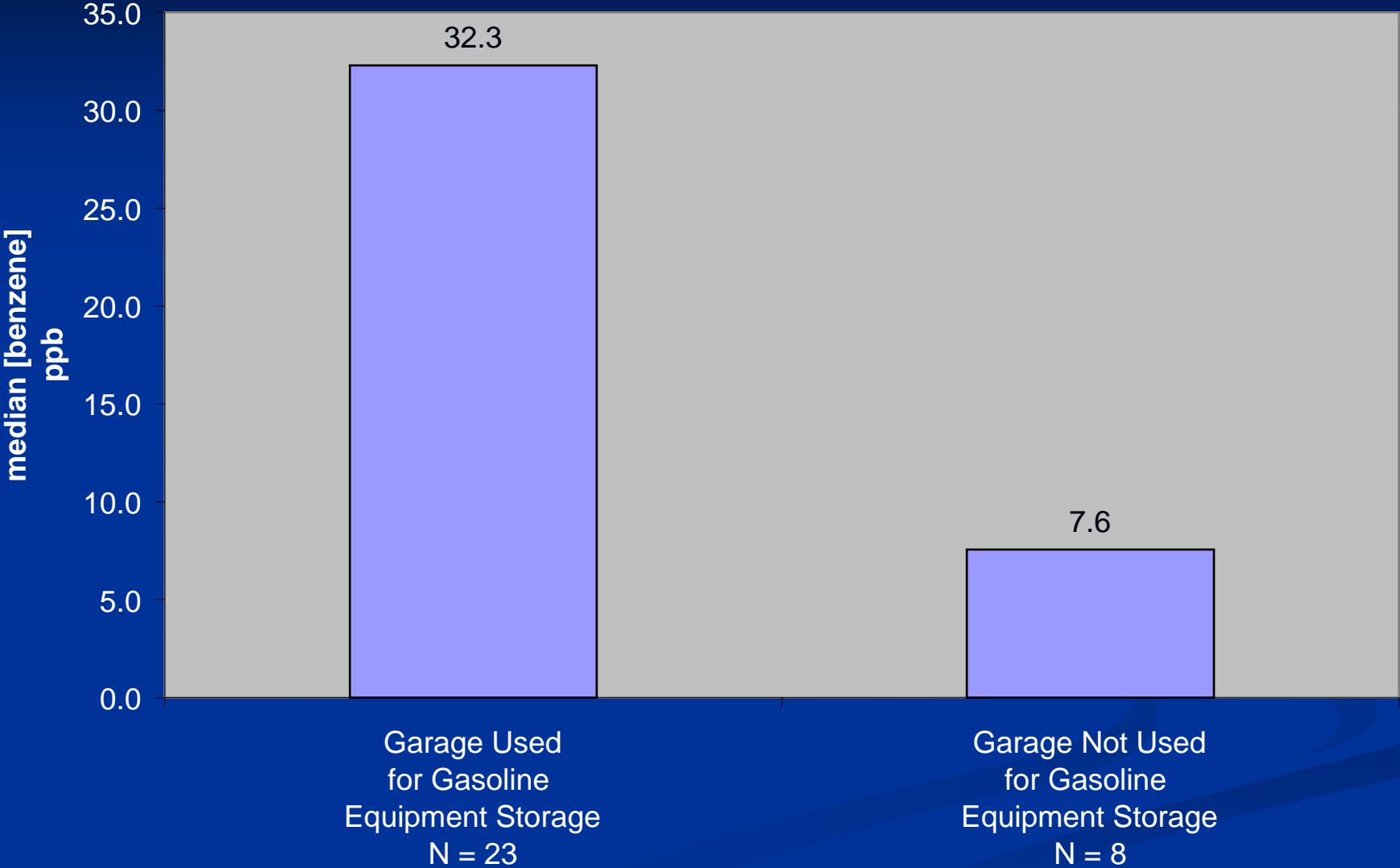
The data do not show a significant association between the benzene level in the garage and:

- The number of vehicles parked in the garage;
- The age of the vehicles in the garage; or
- The number of trips originating from the garage.

Evaporative emissions may be a more important source than exhaust emissions.

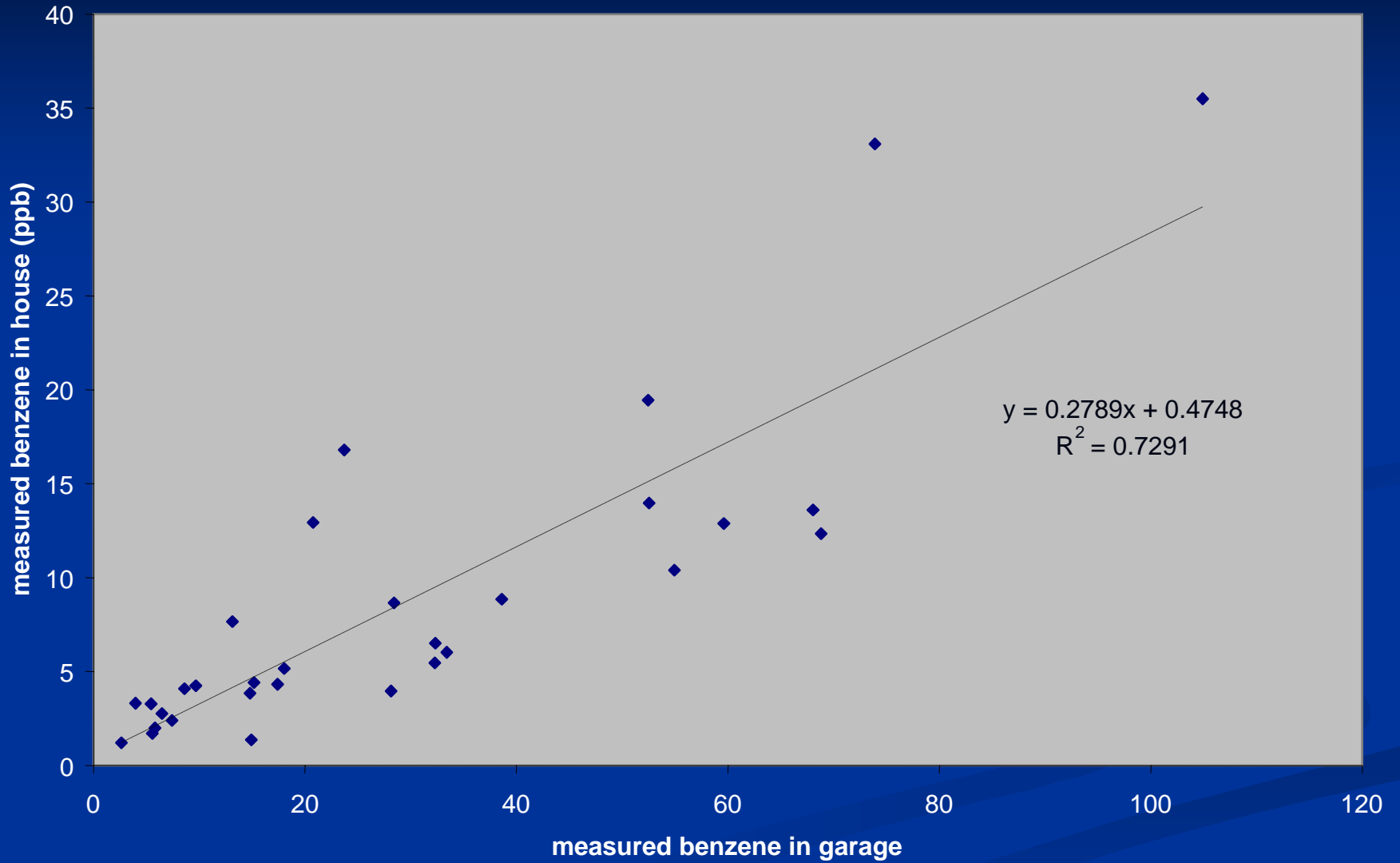


Comparison of Benzene Concentration in the Garage



Having an elevated level of benzene in the garage was a good indicator that benzene levels in the house would also be high.

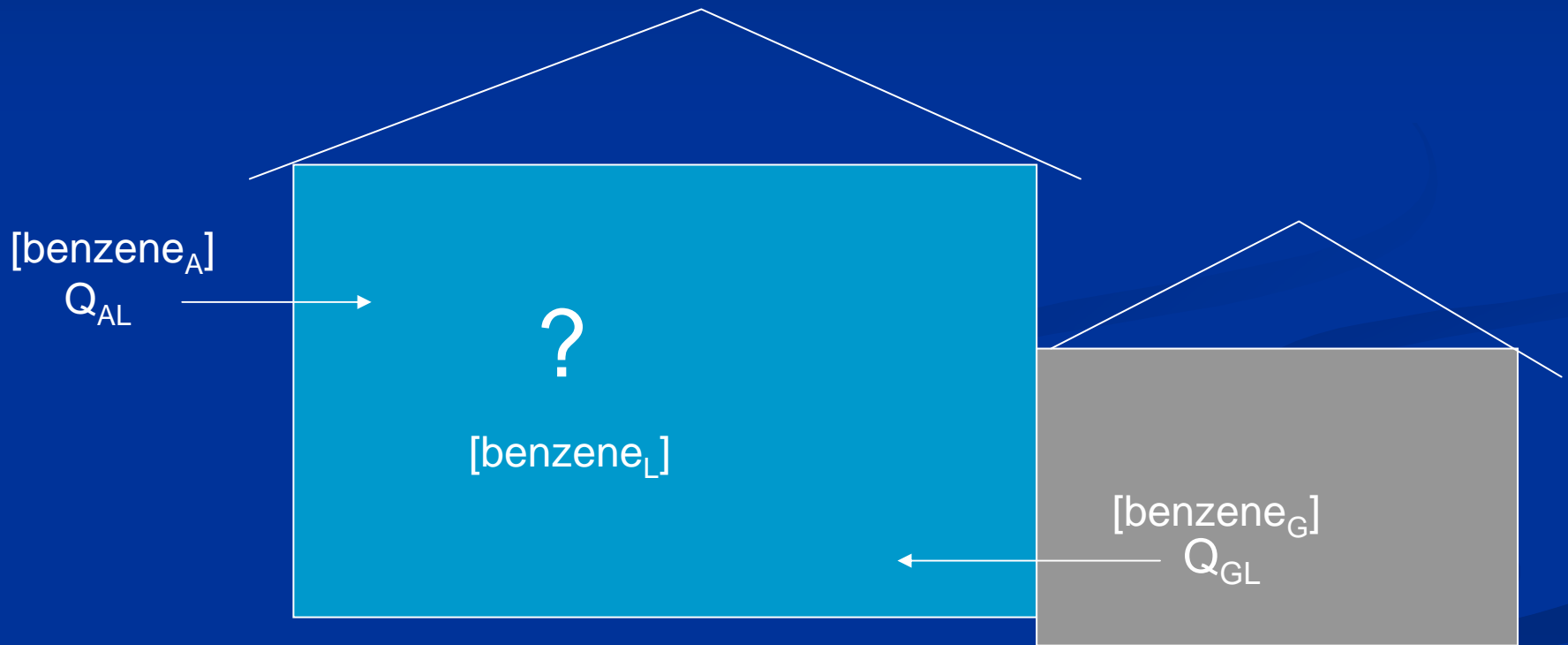
Garage Benzene vs. House Benzene



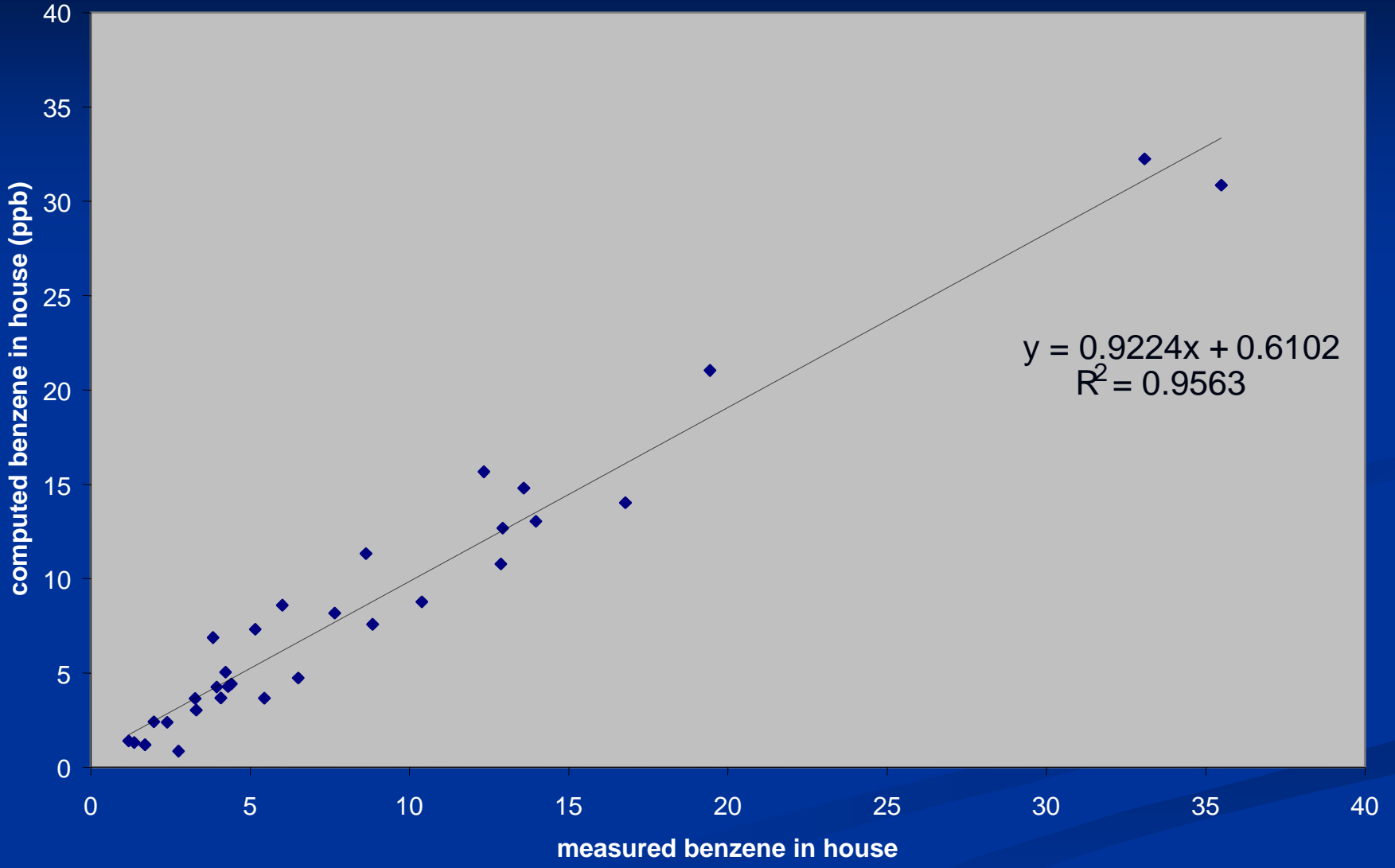
The benzene concentration in the house could be precisely predicted from the garage concentration if the air exchange rate between the garage and house was known.

$[\text{benzene}_L] =$

$$[\text{benzene}_A] \times Q_{AL} / (Q_{GL} + Q_{AL}) + [\text{benzene}_G] \times Q_{GL} / (Q_{AL} + Q_{GL})$$

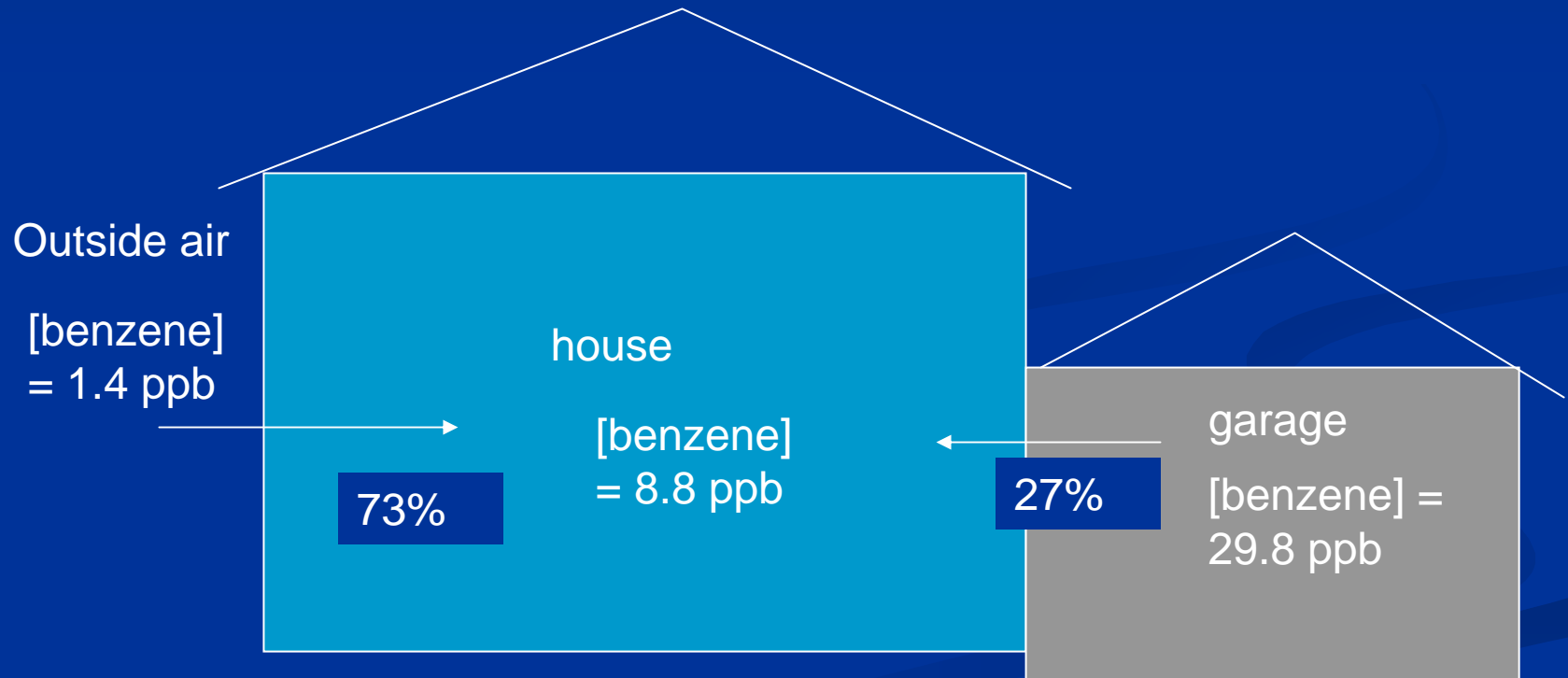


Computed vs. Measured House Benzene



The “average” Anchorage house....

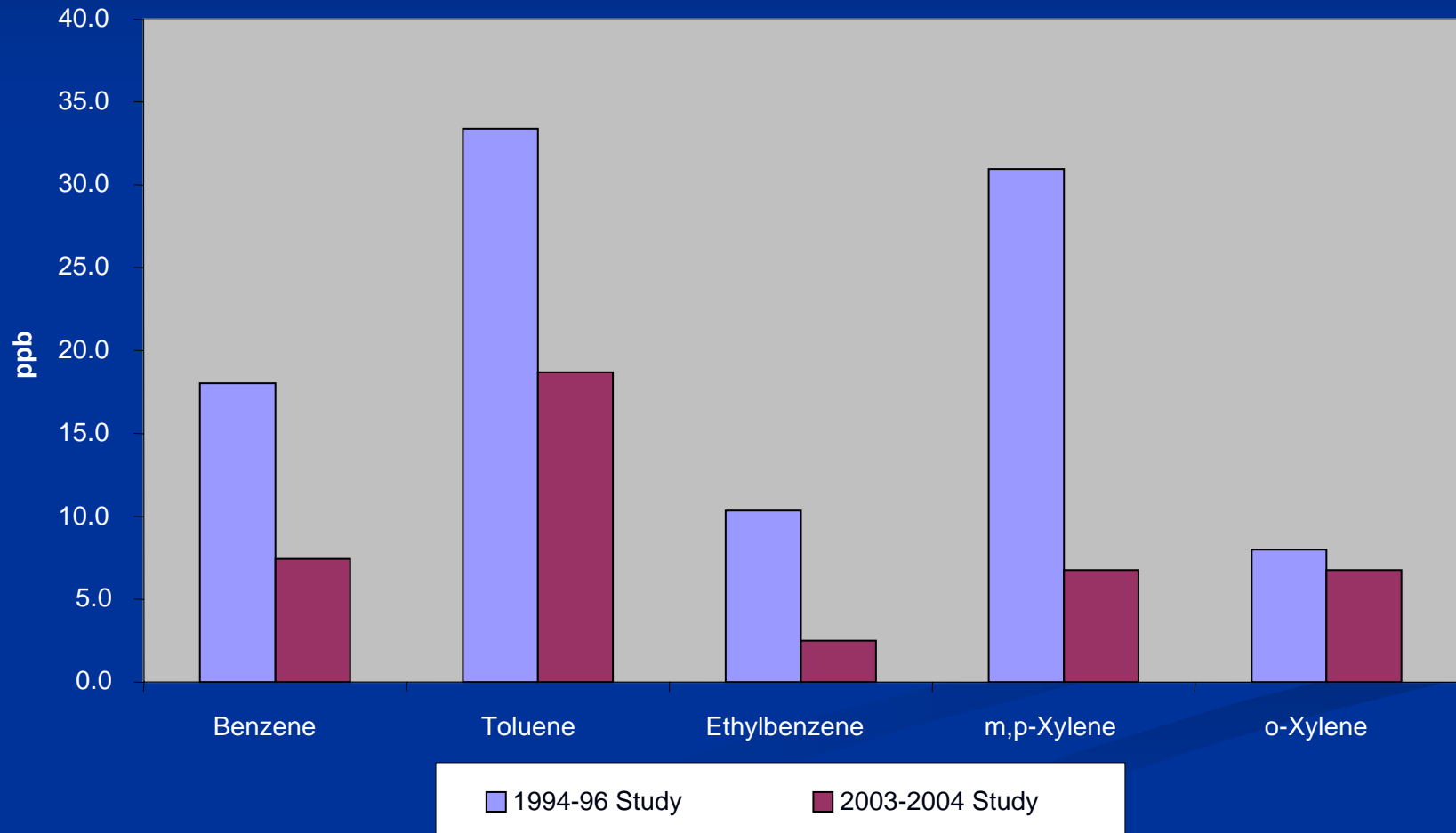
- benzene concentration is 6 times higher than outside
- 27% of air in the house comes from garage
- over 90% of benzene in house comes from the garage



BTEX concentrations dropped considerably between 1994-96 study and 2003-2004 study

Comparison of In-home BTEX Concentrations

1994-94 study vs. 2003-2004 study



Phase 2 – Evaluation of Mitigation Strategies



Candidate Strategies

- Remove gasoline-fueled equipment from garage.
- Modify forced air systems placed in garages to reduce air infiltration
- Ventilate garage to reduce VOC concentrations
- Lower benzene content in gasoline