HOMEOWNER INDOOR AIR QUALITY OPINION SURVEY and FIELD TESTING PROTOCOL DEVELOPMENT PHASE I

Prepared by

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NAHB RESEARCH CENTER

America's Housing Technology and Information Resource

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Prepared for

National Association of Home Builders
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Washington, DC 20005

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ACKNOWLEDGEMENTS

The principle investigator in this project was Craig Drumheller of the NAHB Research Center with significant contributions from Kevin Mo, PhD. and Shelton Cartwright. Technical review provided by Tom Kenney, P.E. Special appreciation is extended to National Association of Home Builders for sponsoring this research and Air Quality Sciences for its technical assistance.

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INTRODUCTION

PURPOSE

The purpose of the Indoor Air Quality Study was to understand homeowners' perceptions of air quality inside their homes and how climate and vintage come into play. In parallel, a field protocol was developed and tested in a pilot study to quantify indoor air quality (IAQ) for homes. The findings of this project provide a basis for a comprehensive, Phase II, field investigation.

BACKGROUND

In December 2003, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) published a residential ventilation standard, *ASHRAE Standard 62.2-2003, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. The new ASHRAE standard requires mechanical (fan powered) ventilation in all homes with the exception of the warmest climates.

A primary concern about the standard within the home building industry is the lack of peer-reviewed scientific research to support its mechanical ventilation requirements. Some standard-setting committee members have acknowledged that the standard was written largely based on "professional experience and the judgment of committee members."

Housing materials and construction techniques have evolved over time, changing housing characteristics. Also, energy-efficiency programs have encouraged the use of air sealing materials. Many of these modern construction methods have found their way into typical construction processes, making newer homes, as a whole, significantly tighter than those built earlier[1]. Little research has been done, however, on the impact of these changes on IAQ.

There are two different perspectives by which indoor air can be evaluated — occupant perceived air quality and quantified levels of air characteristics. The survey portion of the study focused on the former in order to investigate homeowners' subjective evaluation of IAQ in their own houses. Testing protocol development and a pilot study address the latter. Candidates for field testing, Phase II, were identified by a question in the survey to see if they were interested in having on-site IAQ measurement and analysis for the purposes of research.

[1] Chan, W, R et al., Analysis of U.S. Residential Air Leakage Database, LBNL Report #53367, July 2003

SURVEY

The primary vehicle for gathering data for this study was an Internet-based survey. The survey was open to single-family detached homeowners throughout the United States, including a variety of construction types and vintages. Survey questions (see Appendix A for complete survey) included such topics as:

- household profile (e.g., occupants' age, income, education, etc.)
- house characteristics (e.g., type, size, location, orientation, building materials, natural/mechanical ventilation)
- lifestyle (e.g., smoking, pets)
- subjective occupant perceptions of IAQ
- health aspects relating to IAQ

The survey also asked if the respondents were willing to volunteer for a site survey (Phase II) to gather quantitative information on their houses. Over 60 percent of participants indicated they would consider site testing of their homes.

The survey was conducted December 28-30, 2004. A total of 3,111 surveys were completed by owners of single-family detached homes throughout the United States. To ensure a significant representation of newer homes, the survey was reopened briefly on December 31st for homes constructed after 1990.

Validity

To verify the survey was representative of the housing population, comparisons were made between characteristics of the IAQ survey group and the general population as determined by the American Housing Survey for the United States: 2003 (AHS). Below are tables representing direct comparisons of income, house age, census region, and house size. The homes selected from the AHS were owner-occupied, single-family detached homes. Other than a second effort to obtain additional newer homes in the IAQ survey, no valid surveys were altered, adjusted, compensated, or intentionally skewed in any manner.

Income Comparison

Income comparisons between the IAQ Survey and the AHS are nearly identical.

Table 1: Income Comparison

Income Range	IAQ Survey	AHS
<$20,000	18%	16%
$20K-29,999	11%	11%
$30K-39,999	11%	11%
$40K-49,999	9%	9%
$59K-59,999	9%	9%
$60K-74,999	14%	14%
$75K-99,999	10%	10%
$100K+	18%	19%

House Vintage Comparison

The age of the surveyed homes for this study is very much in line with the AHS. Because the IAQ survey was reopened to get a larger sample of post-1990 homes, a slight bias toward newer homes can be seen.

Table 2: Age of Home Comparison

Year Built	IAQ Survey	AHS
Pre-1930	8%	11%
1930s	3%	4%
1940s	6%	6%
1950s	14%	12%
1960s	13%	13%
1970s	17%	18%
1980s	12%	13%
1990s	20%	16%
2000s	8%	6%

Regional Comparison

To ensure regional representation, the comparison was made between the four main Census Regions. AHS regional population distribution very closely matched the IAQ Survey.

Table 3: House Census Region Comparison

	Region	IAQ Survey	AHS
Northeast:	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, and New Jersey	18%	18%
Midwest:	Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Kansas, Nebraska, North Dakota, and South Dakota	27%	25%
South:	Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Kentucky, Arkansas, Louisiana, Oklahoma, and Texas	36%	37%
West:	Montana, Wyoming, Colorado, New Mexico, Arizona, Utah, Idaho, Alaska, Washington, Oregon, Nevada, California, and Hawaii	19%	20%

House Size

House size has a bias toward the mean square footage in the IAQ survey. Homes in the 1,000 to 2,000 square foot range are over represented in the IAQ survey by 7 percent. But, since the overall perceived IAQ for homes in this range is only 1 percent higher than the average perceived IAQ (69% vs. 68% Good or Very Good IAQ), the research team did not believe the bias affected the results.

Table 4: House Size Comparison

Square Footage	IAQ Survey	AHS
Below 1,000	5%	9%
1,000-1,499	27%	25%
1,500-1,999	31%	26%
2,000-2,499	19%	18%
2,500-2,999	10%	9%
3,000-3,999	6%	9%
4,000+	3%	5%

Observations

Perceived IAQ was based primarily on the responses to question 32 – "How would you rate the quality of the air you breathe?" The optional responses were Very Poor, Poor, Neutral, Good, and Very Good. Throughout the analysis, a Good or Very Good response was considered a "perceived high indoor air quality." Although this is the response to only one question, the results correlated highly with a series of responses to questions on indoor conditions. It should also be noted that this is strictly the opinion of the homeowners and may or may not be representative of the actual quality of the indoor air.

- Over two-thirds of those surveyed believed that their indoor air quality is either Good or Very Good.
- Perceptions of IAQ by homeowners were strongly related to thermal comfort. The survey responses had consistently high correlations between characteristics such as air movement, temperature, and perceived indoor air quality.

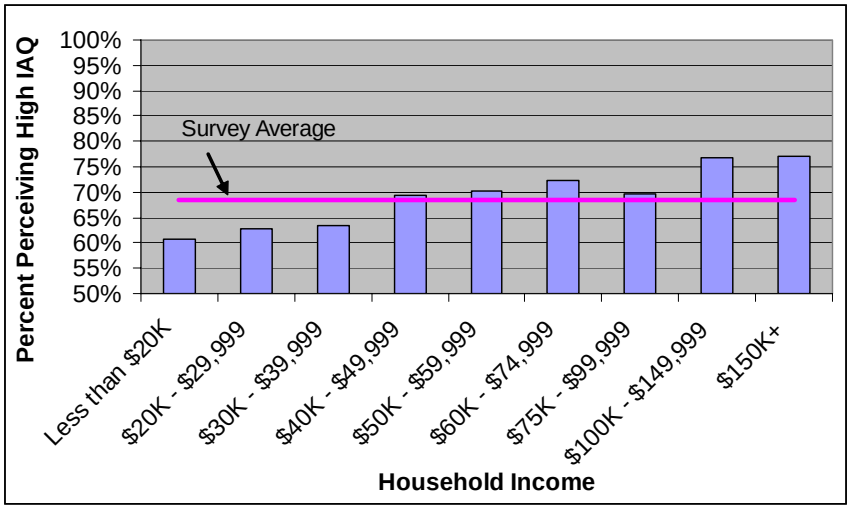

Figure 1: Household Income

Household Profile

The IAQ survey uncovered a trend that households with higher incomes are more likely to have a perception of higher IAQ. All income groups with incomes below $40,000 had a below average percentage of homeowners perceiving their IAQ as high.

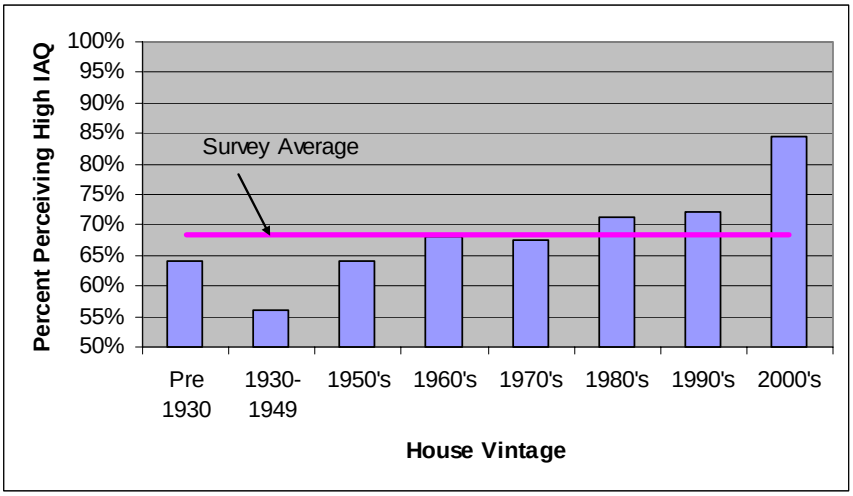

Figure 2: Age of Home

House Characteristics

Houses constructed prior to 1960 showed a noticeably lower perceived IAQ compared to newer homes. Homes built since 2000 showed markedly higher perceptions to IAQ.

Homes below 1,000 square feet showed a significantly lower level of perceived IAQ.

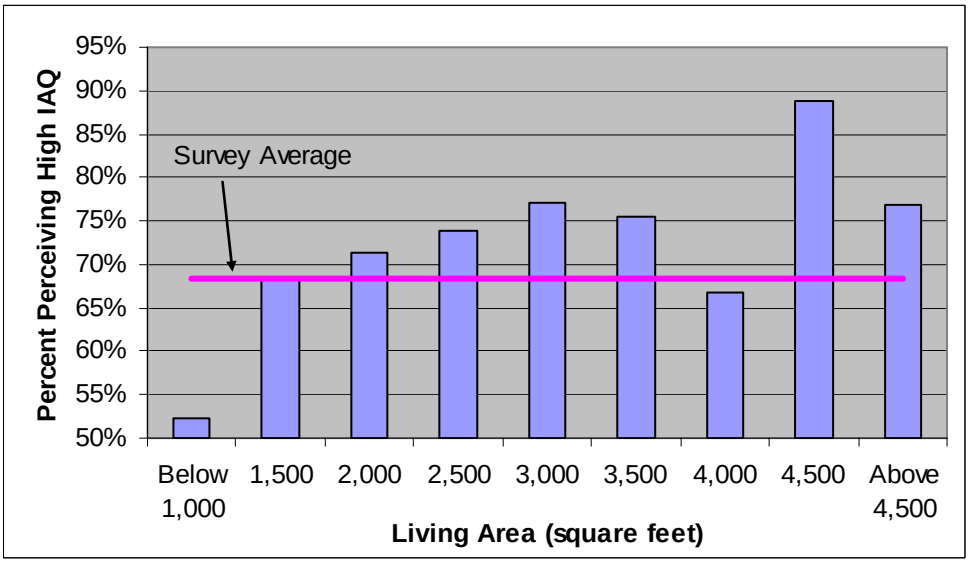

Figure 3: IAQ Perception by House Size

Figure 4 shows households that perceived their IAQ to be high did not appear to change their opinion on IAQ based on test results. This indicates that homeowners do not associate Radon levels with IAQ.

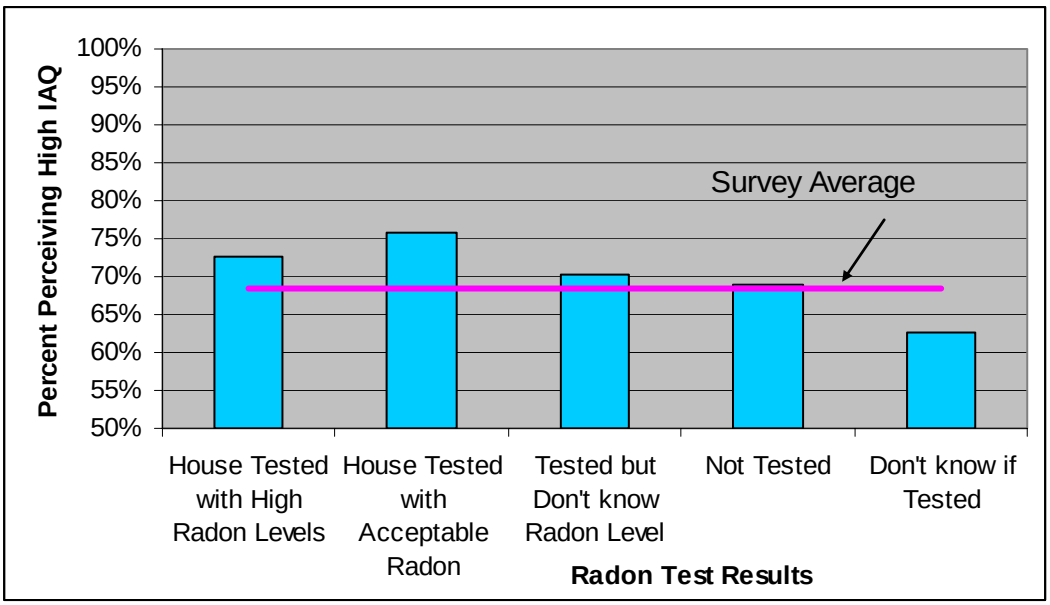

Figure 4: Perceived High IAQ Homes and Radon

Lifestyle

Far fewer smokers perceived the IAQ to be high (53%) as compared to non-smokers (73%).

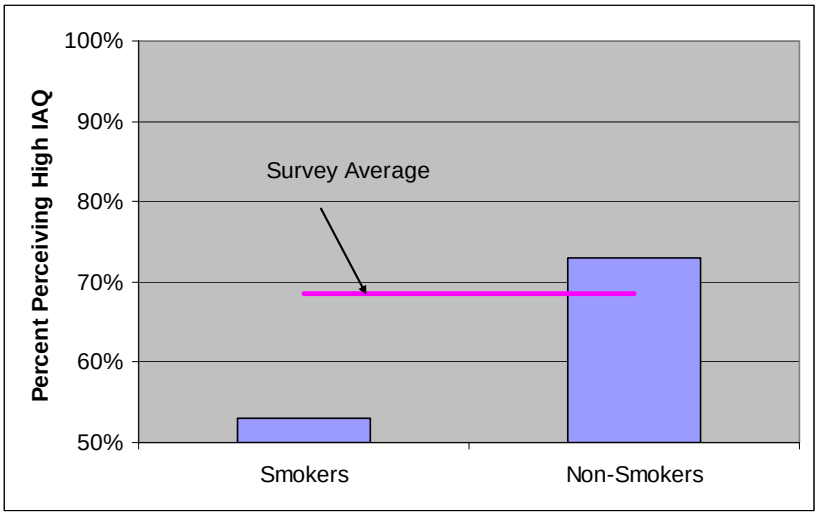

Figure 5: Smokers

Although households with pets had a slightly lower perceived IAQ, it is not enough to be considered significant.

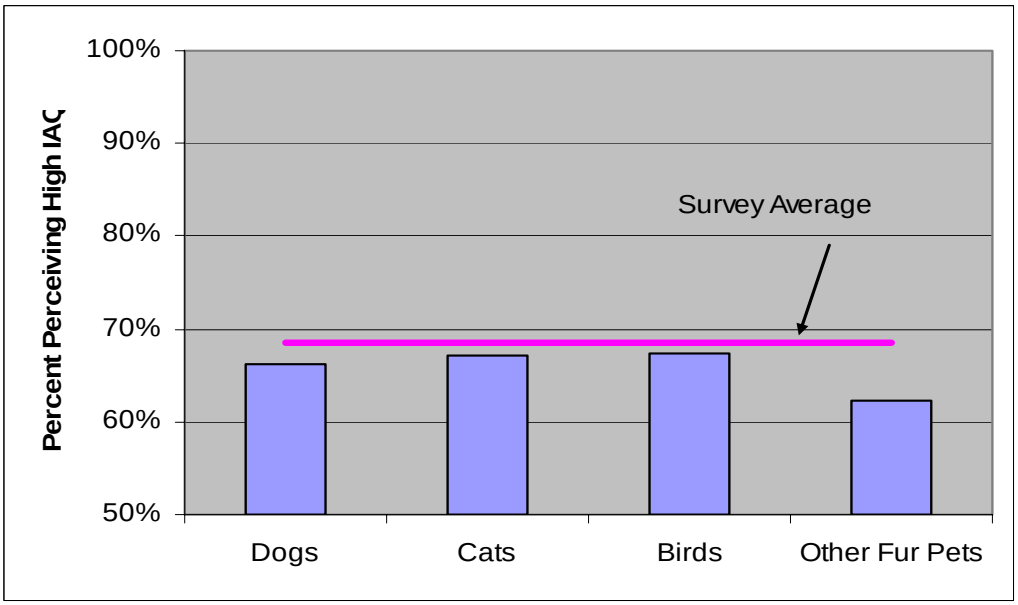

Figure 6: Pet Owners

Window Usage

Window usage has been traditionally thought to be a solution to poor IAQ. If windows are not used for ventilation in very tight homes, some have argued that mechanical ventilation should be required in order to provide an adequate supply of fresh air. The survey results indicate that over half of the respondents use their windows "whenever possible" in spring, summer, and fall. Roughly three out of four surveyed use windows "often" or "whenever possible" in the non-winter months.

Table 5: Window Usage

	Summer	Fall	Winter	Spring
Whenever Possible	57%	52%	26%	53%
Often	14%	24%	6%	27%
Seldom	18%	17%	37%	15%
Never	11%	6%	30%	6%

Subjective

A series of questions were asked of each respondent about the perceptions regarding his or her residence (questions 33-48). These questions were asked to determine the relationship between the overall perceived IAQ and more specific characteristics.

A number of determinations were made based on the responses:

- Winter IAQ is more important to homeowners than summer IAQ.
- The two characteristics that most closely correlated with the perception of high IAQ were a good supply of fresh air and quickly dissipating odors.
- Of all the rooms in the house, musty smells in the family room or living room were the highest indicator that the homeowner would perceive IAQ to be Poor.
- Over 80 percent of people who felt their air conditioner provided Very Good daily comfort also thought their overall IAQ was high. This is compared to only 39 percent who thought their air conditioner performance was Neutral to Very Poor.
- 81 percent of those surveyed did not believe that their house had an IAQ problem.
- When correlating overall perception of IAQ with a variety of air cleaning equipment (e.g., furnace filters, high-efficiency filters, air purifiers, ozone generators), users of ozone generators were the most likely to be satisfied with their IAQ.
- It appears that the people who are least knowledgeable about their home have a lower perception of IAQ. Thirteen questions were asked with regard to house

characteristics that had a multiple choice option of "Don't Know." Every one of these questions had the lowest perceived high IAQ percentage.

Health

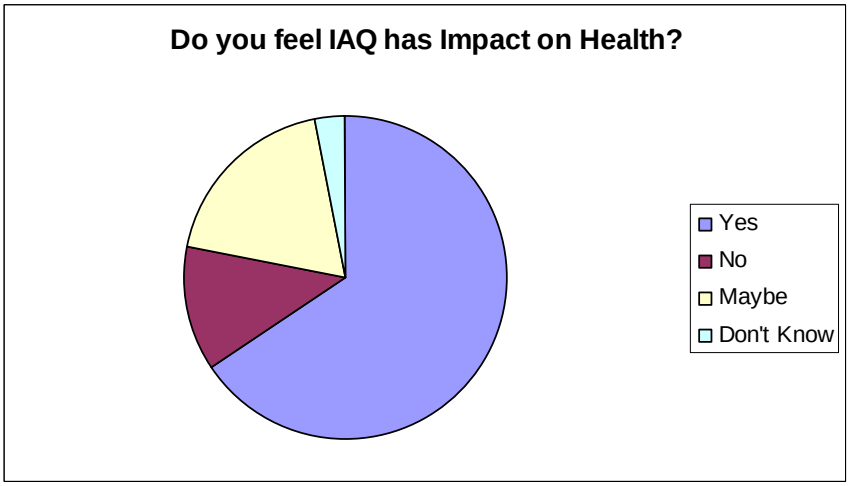

Figure 7: Health Survey

Only 12 percent of those surveyed believe that IAQ does not have an impact on health.

Respondents who claimed to have one of six health problems commonly perceived as being related to IAQ were asked if they believed *their* health problems were IAQ related. Over half (52%) believed Nose Bleeds were affected by IAQ. One in four believed their Skin Rashes were related to IAQ. This was followed with similar responses regarding Hay Fever (23%), Asthma (21%), Colds (19%), and Headaches (16%).

Climate

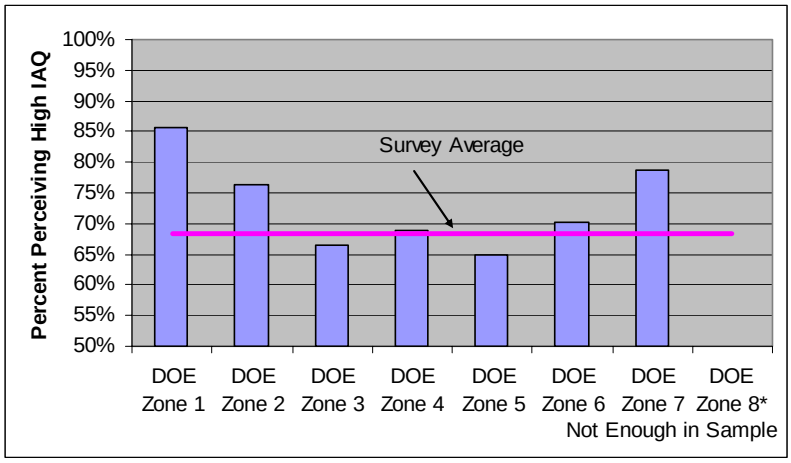

Figure 8: Climate Type

The U.S. Department of Energy (DOE) created a climate zone map (Figure 9) that has been incorporated into the 2006 International Energy Conservation Code (IECC). This map divides the country into eight climate zones and three moisture zones. Figure 8 shows that Zones 3, 4, and 5 were at or below the survey average for high IAQ with the more extreme climates rating higher.

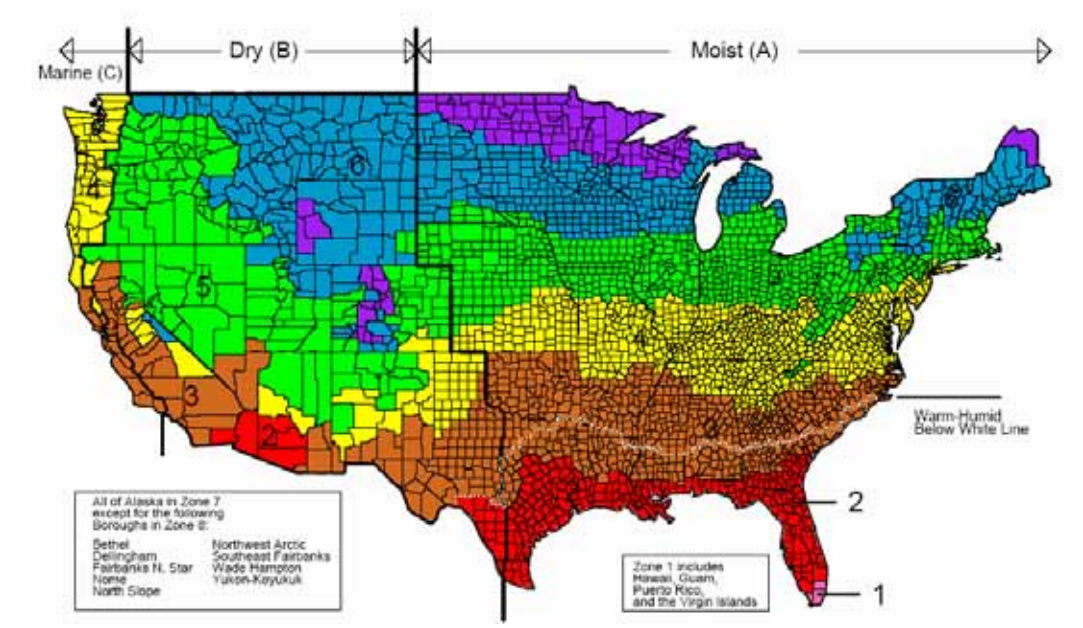

Figure 9: DOE Climate Zone Map

How IAQ Is Perceived

Based on the results of the IAQ survey, it appears most people believe their homes do not have a problem with indoor air quality (81%). Perception of Good IAQ is based largely on comfort, and the main driver of this perception is HVAC performance.

PILOT INVESTIGATION ON INDOOR AIR QUALITY

From April 18-22, 2005, the NAHB Research Center staff measured air exchange rate, mold, formaldehyde (HCHO), respirable suspended particulate (RSP), radon concentration, and volatile organic compounds (VOCs) in five single-family houses in Maryland. The objective of the investigation was to test a protocol for a nationwide IAQ survey in residential buildings. One of the initial

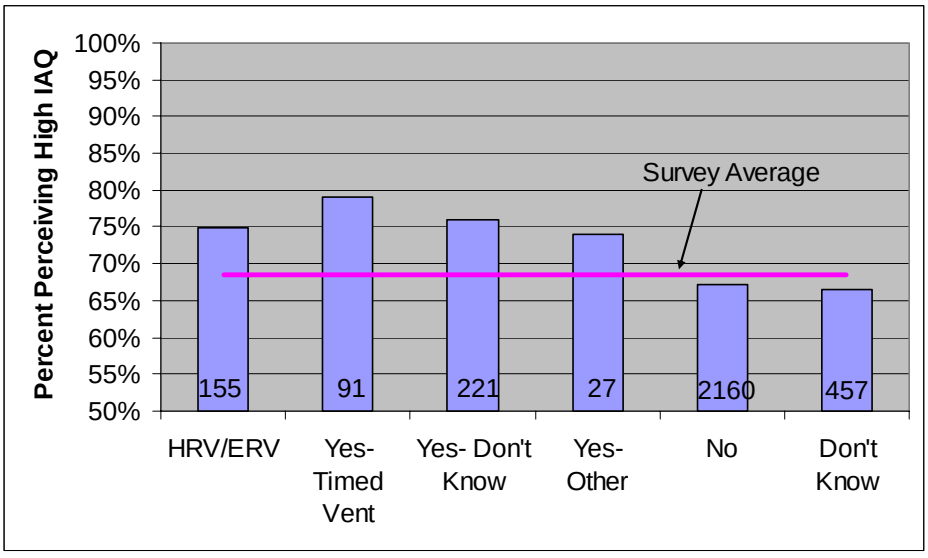

Figure 10: Perception of IAQ

goals was to determine if there was a strong correlation between air tightness and IAQ. Below is a summary of the pilot investigation activities and preliminary results.

TESTING PROCEDURE

1. Sampling Locations

The five houses were chosen from among the NAHB Research Center staff. An email notification was sent to all staff in order to recruit volunteers whose homes met the following criteria:

- Single-family house
- House to be at least two years old
- Agree to take an online IAQ survey prior to selection
- Within 10 miles of the Research Center facility (exception was made for House #4)

Sixteen people volunteered their homes; five were chosen based on online survey results and house characteristics shown in Table 6.

Table 6: Characteristics of Five Test Houses

House ID	Year Built*	Enclosed Area*	Zip Code
1	1950	816 s.f.	20740
2	1963	1,583 s.f.	20715
3	1977	1,524 s.f.	20716
4	1987	2,216 s.f.	20736
5	2002	1,817 s.f.	20716

* Source: public database by Maryland Department of Assessments and Taxation

2. Testing Methods

Mold testing for each house used the non-culture analysis method. A Burkard Air Sampler (Figure 11) pulled air onto greased slides. The slides were then sent to the Air Quality Sciences (AQS) lab for analysis of mold spores. The sampling duration was 8 minutes indoors and 6 minutes outdoors.

Figure 11: Burkard Air Sampler

Two sampling methods were tested to measure formaldehyde concentrations: Dräger absorbent tubes and solid absorbent cartridge TO-11A (Figure 12). Though the Dräger method could generate instant results, initial field measurements showed that it was not sensitive enough to detect relatively low-level

formaldehyde in the houses. Therefore, the TO-11A method was used at all houses. Air was collected onto solid sorbent cartridges treated with dinithrophenylhydrazine using pre- and post-calibrated air sampling pumps. The sampling duration was 60 minutes and the cartridges were then sent to the AQS lab for readings.

Figure 12: Formaldehyde Sampling Pump

VOC testing applied the active sampling using solid sorbent collection media, followed by analysis using thermal desorption/gas chromatography-mass spectrometry (TD/GC-MS). Total volatile organic compounds (TVOCs) and Top-20 individual VOCs with highest concentrations were obtained through the AQS lab. The sampling period was 90 minutes indoors and 60 minutes outdoors.

Figure 13: VOC Vacuum Pump

A TSI model 8520 Aerosol Monitor (Figure 14) was used to measure particulate concentrations. Blower door tests were conducted to obtain air exchange rates at 50 Pascals.

A radon test tool kit for short-duration sampling (24-72 hours) was used for radon testing. The radon canister was set up after all other testing was completed. This test required the homeowner to close up the canister within the 24- to 72-hour timeframe and mail it in a self-addressed stamped envelope, provided by the researchers, within three days.

There were four instances where re-testing was required because of problems related to properly returning the radon canisters. This prompted an investigation of alternative measurement methods. The Research Center owns a radiation meter that can, with a calibrated scintillation tube, provide real-time radon readings, which would be the preferred method of radon measurement for a large-scale field evaluation.

Figure 14: TSI Model 8520 Aerosol Monitor

RESULTS

There are no defined federal regulations concerning residential IAQ. However, there are standards and

guidelines recommended by international health associations, industry organizations, state governments, and private programs and researchers. Interpretations of measurement results were based on the cited standards or guidelines that the researchers deemed appropriate in the context of residential buildings.

Figure 15: Outdoor Air Sampling of Formaldehyde and VOC

Volatile Organic Compounds (VOCs)

Studies by EPA and other researchers found that VOCs were common in the indoor environment. Some VOCs are irritants and could result in headache; eye, nose, and throat irritation; and dizziness. At high concentrations, some VOCs are toxic.

The concentration of TVOCs in a building is a good indicator of the presence of volatile organic compounds. ASHRAE[2] asserts that TVOCs higher than 3,000 ug/m^3 would cause significant odor. A study by Malhave[3] had further findings on TVOC levels as follows:

- <200 ug/m^3, no irritation or discomfort expected
- 200 ~ 3,000 ug/m^3, irritation and discomfort possible
- 3,000 ~ 25,000 ug/m^3, discomfort expected and headache possible
- >25,000 ug/m^3, toxic range where other neurotoxic effects may occur

Figure 16 shows the TVOC levels in the five houses. The readings of TVOC in all the houses were over 200 ug/m^3. The highest level was 626 ug/m^3. Based on the Malhave suggestions, there might be irritation and discomfort in the five houses.

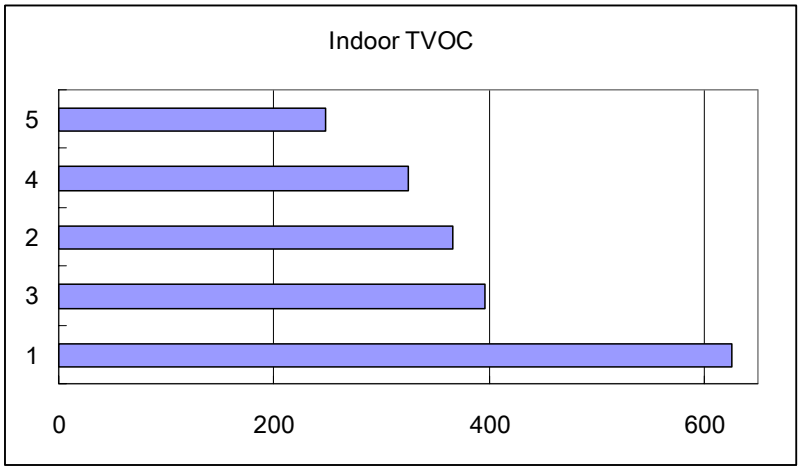

Figure 16: TVOC in the Five Houses (ug/m^3)

Top-20 individual VOCs with highest concentrations were also identified in this part of the study. However, there is no IAQ standard on threshold

[2] ASHRAE Fundamentals Handbook. 2001. P9.10
[3] Malhave L. Indoor Air Quality in Relation to Sensory Irritation due to VOCs. ASHRAE Transaction 1992.

value in residential buildings. The American Conference of Governmental Industrial Hygienists (ACGIH) published the 2005 Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs). Only three individual VOCs were common in all five houses, two of which were listed by ACGIH in its TLV or BEI tables. None was higher than maximum allowable level.

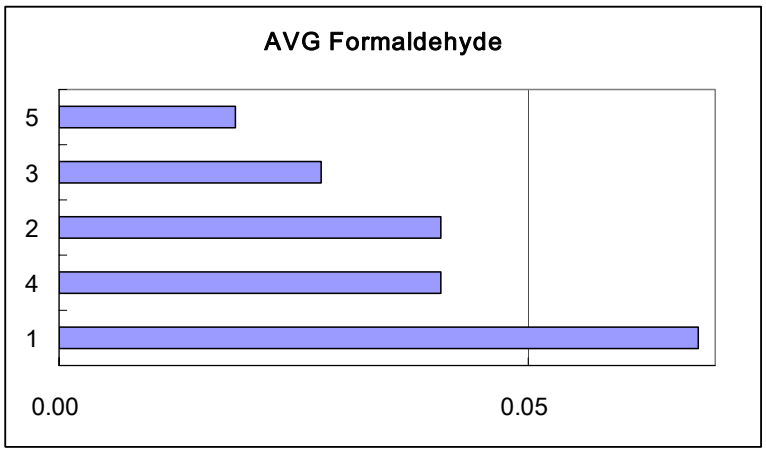

Figure 17: Average Formaldehyde Concentrations in the Five Houses

Table 7: Common Individual VOCs Found in Test Houses

CAS#	VOC	1	2	3	4	5	ACGIH Critical Effect(s)
111-76-2	2-Butoxyethanol (ppb)	1.2	1.8	1.4	1.4	0.8	Irritation. < 20k ppb
108-88-3	Toluene (ppb)	1.1	5.1	1.1	1.4	2.0	Threshold value (50,000 ppb)
541-02-6	Decamethylcyclopentasiloxane	34.1	49.3	7.2	19.8	23.8	Not defined

Formaldehyde

Formaldehyde has been classified as a probable human carcinogen by the EPA. Airborne formaldehyde is an irritant to the conjunctiva and upper and lower respiratory tract. Symptoms may range from burning or tingling sensations in eyes, nose, and throat to chest tightness and wheezing. Urea-formaldehyde resin-based particle and chipboard products are primary sources of formaldehyde.

OSHA estimates that approximately 2.2 million workers are exposed to formaldehyde at levels of 0.10 ppm or greater. The permissible exposure limits (PELs) set by OSHA for formaldehyde in the workplace are 0.75 ppm measured as an 8-hour, time-weighted average (TWA). The action level is 0.50 ppm. The Canadian standard (Health Canada) for Formaldehyde is 0.10 ppm and its target level is 0.05 ppm.

Figure 17 shows that the formaldehyde level in House 1 was higher than the target level specified by the Canadian standard, but lower than the OSHA standard.

Mold

There is no federal or state standard on airborne concentrations of mold contaminants. While California became the first U.S. state to address public health risks from mold in

commercial and residential buildings[4], a study by the Institute of Medicine, an arm of the U.S. National Academy of Sciences, suggested that it is impossible to "establish a clear causal relationship between mold exposure and these illnesses."[5]

Table 8 lists fungal spores identified both inside and outside of the five houses. The fungal spores were classified into four groups (leaf surface, water damage, soil mold, and other molds). No fungal spores were identified in the Water Damage group and the soil mold accounted for a low proportion, which suggested that the five houses were without mold growth, water damage, or moisture problems, based on existing research findings[6]. There is no widespread agreement on acceptable levels of total airborne fungi, nor is there a set of criteria or threshold limits to judge individual fungal spore.

Table 8: Categorized Fungal Spores (Counts and Percentage)

	Leaf Surface		Soil Mold		Others		Grand Total
	Particles/m3	%	Particles/m3	%	Particles/m3	%	
4 (inside)	**175**	**23%**	**450**	**59%**	**138**	**18%**	**760**
4 (outside)	1,050	80%	100	7%	167	13%	1,320
1 (inside)	**125**	**33%**	**188**	**50%**	**63**	**17%**	**380**
1 (outside)	2,233	81%	150	5%	383	14%	2,770
5 (inside)	**900**	**49%**	**638**	**35%**	**288**	**16%**	**1,830**
5 (outside)	2,450	74%	167	5%	683	21%	3,300
3 (inside)	**1,338**	**34%**	**2,175**	**56%**	**375**	**10%**	**3,890**
3 (outside)	19,333	98%	150	1%	250	1%	19,730
2 (inside)	**2,100**	**83%**	**125**	**5%**	**313**	**12%**	**2,540**
2 (outside)	11,533	98%	33	0%	183	2%	11,750

Some researchers believe that the ratio of indoor to outdoor molds (I/O ratio) as well as the ratio of leaf surface fungi to water indicator fungi and/or soil molds is a good indicator for accurate assessment. Figure 18 shows the ranking of I/O ratio of fungal spores.

[4] Environmental Science and Technology website. http://pubs.acs.org/subscribe/journals/esthag-w/2001/nov/policy/kc_mold.html. 6/7/2005
[5] Environmental Science and Technology website. http://pubs.acs.org/subscribe/journals/esthag-w/2004/jun/policy/kc_mold.html. 6/7/2005
[6] Horner, W. E., A.G. Worthan and P.R. Morey. Air- and Dustborne Mycoflora in Houses Free of Water Damage and Fungal Growth. Applied and Environmental Microbiology. Nov. 2004. pp 6394-6400.

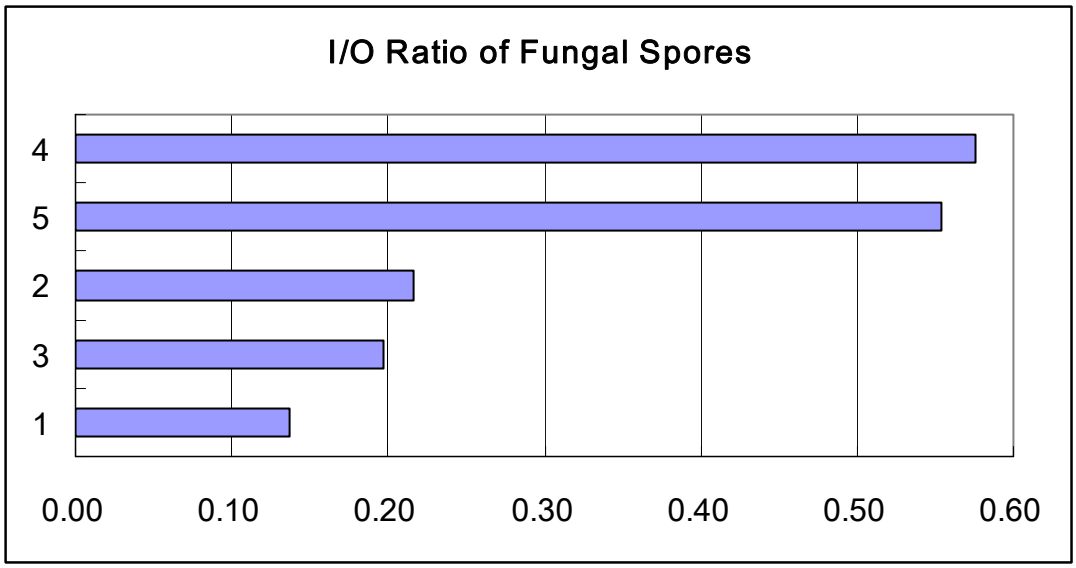

Figure 18: I/O Ratios of Fungal Spores in the Five Houses

Particulate Matter

Particulate matter (PM) is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Essentially, atmospheric particles are grouped into two distinct size ranges — fine particle band (0.1~1 (micron) µm), and coarse particles (5~50 µm). Particles less than 10 um in diameter (PM10) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 µm) in diameter (PM2.5) are referred to as fine particles and are believed to pose the greatest health risks. Figure 19 illustrates the relative size of common particulate matter.

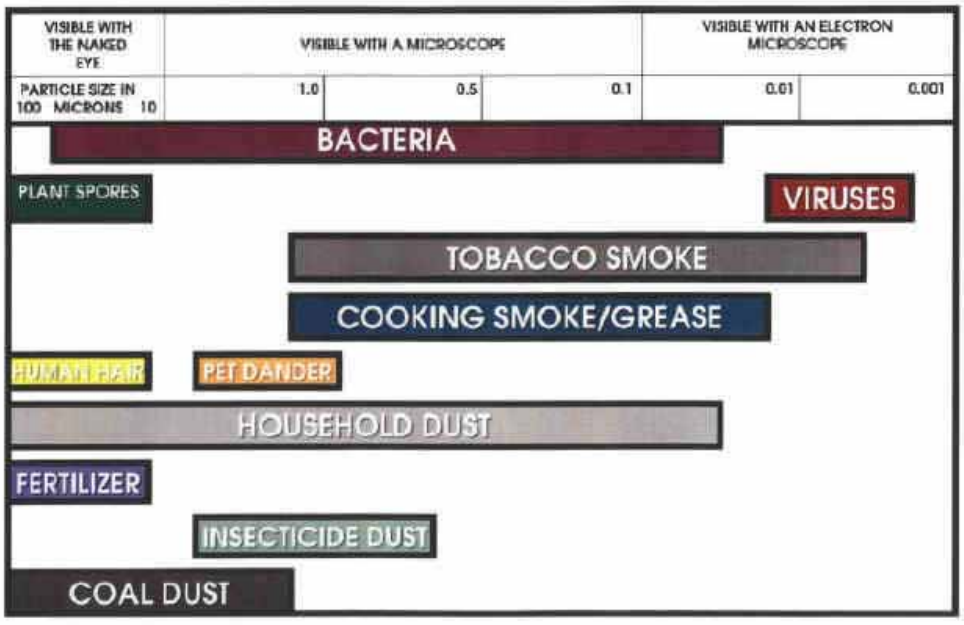

Figure 19: Relative Sizes of Various Particulate Matter

There are several standards and guidelines on outdoor particulate matter but little in relation to indoor air. ASHRAE Standard 62-1989 has a guideline (PM10) for outdoor average concentrations at 50 ug/m^3 over one year and 150 ug/m^3 over 24 hours. EPA

sets the same standard for PM10 and proposed levels for PM2.5 at 0.65 ug/m^3 over 24 hours and 0.15 ug/m^3 over one year. Particle concentrations (PM10) for this testing were measured by TSI model 8520 Aerosol Monitor. Table 9 shows average PM indoor and outdoor levels over 60 minutes.

Table 9: Average Particulate Matters over 1 hour (PM10) (ug/m^3)

House	Indoor	Outdoor	I/O ratio
2	63	47	1.34
1	54	62	0.871
3	25	36	0.694
4	10	16	0.625
5	20	34	0.588

Radon Concentrations

A radon testing toolkit was ordered from RadonHomeTest.com to obtain a quick sample of radon concentrations. The sampling duration was 24 to 72 hours. Houses 4 and 5 showed the highest readings and were re-tested to reduce the possibility of randomness. The EPA recommended threshold value is 4 pCi/L. Figure 20 shows the radon concentrations. Only Houses 1 and 3 were below the value. Houses 4 and 5 were more than five times the threshold value.

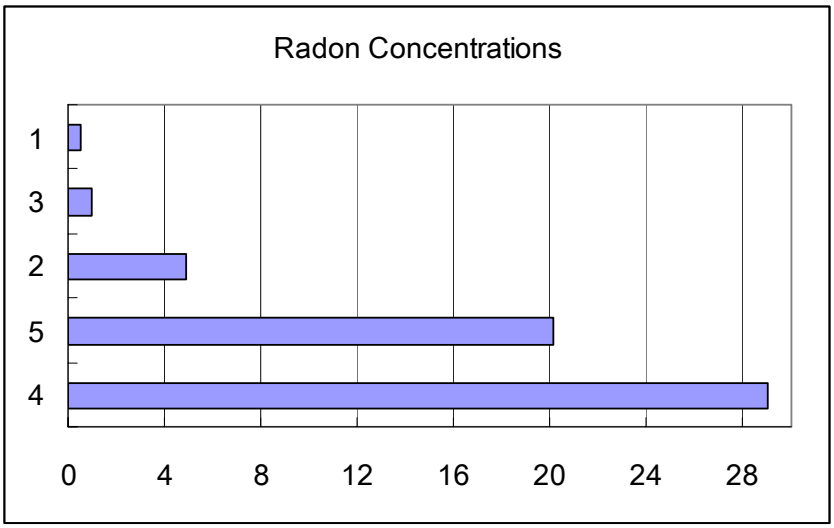

Figure 20: Radon Concentrations in the Five Houses (pCi/L)

Air Tightness

The pilot investigation evaluated the air tightness in the five houses. The air exchange rates at 50 Pascals were obtained and converted to natural air exchange (ACH_{nat}) rates, shown in Figure 21.

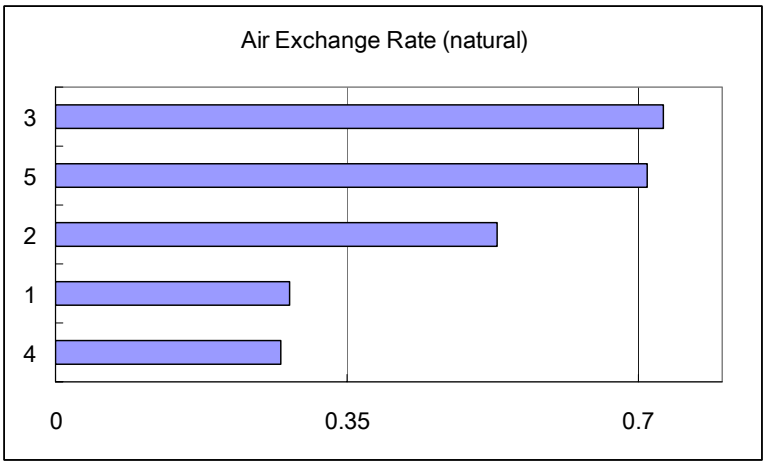

Figure 21: House Air Tightness Results

Preliminary Results

The sample size was too small to draw statistically significant conclusions. However, some observations were made with respect to the relationship between air tightness and IAQ. Relatively, House 1 would be considered Tight at less than 0.35 ACH_{nat}, and House 5 was would be considered Leaky with a natural air exchange rate above 0.7. Their related IAQ indicators contrasted one another, as shown in Table 10.

Table 10: Contrast of IAQ Indicators between Two Houses

	House 1 Tight	House 5 Leaky	Comments
Leaf fungal spores	Lowest	2nd highest	Outside source
Radon	Lowest	2nd highest	Outside source
Formaldehyde	Highest	Lowest	Inside source
TVOC	Highest	Lowest	Inside source
Particle (I/O)	2nd highest	Lowest	Inside/outside

As the table illustrates, the Tight house had a lower level of outside pollutants but a higher level of inside pollutants, and the leaky house performed conversely. The results of the pilot investigation were not conclusive that tighter houses worsen indoor IAQ; this has to be put into the context of source of pollutants (indoor vs. outdoor).

Houses 2, 3, and 4 showed mixed results that weakened the observation to some extent. A larger sample size is needed to reach a statistically significant conclusion.

OBSERVATIONS

Interpretation of residential IAQ results is, to a large extent, dependent on researchers' heuristic experience and choice of other related standards that might not be appropriate to the context of residential buildings.

The investigation protocol was validated and modified, and made ready for a large-scale investigation in the future. In addition, some preliminary results provided a basis for future investigation to identify the relationship between IAQ and air tightness.

CONCLUSIONS

One of the most distinct trends captured in the survey is the relationship between perceived IAQ and house age. Homeowners perceive that the IAQ has become consistently higher in newer homes compared to earlier vintages. This implies that newly constructed homes are perceived to have a higher IAQ than ever before. Other determining factors for higher perceived IAQ include higher incomes, larger homes, and no smokers in the home.

Homeowner perception of IAQ is very comfort oriented (temperature, HVAC performance). Although comfort and air quality can easily be confused, the traditional IAQ definition goes beyond these items to the physical make-up of the air (e.g., moisture, VOCs, particles, etc.). This shows that there is a need to compare IAQ perceptions to that of actual measurement of household air in order to better understand the relationship between the two.

A testing protocol was developed and pilot tested under the scope of this project that will allow for a large-scale field investigation on a statistically significant sample of homes.

The survey generated nearly 2,000 leads throughout the country that are amenable to having on-site IAQ testing.

Fine tuning that occurred on the proposed protocol and numerous candidates identified for on-site testing will allow for timely progress in follow-on, Phase II, field investigation.

APPENDIX 1: SURVEY QUESTIONNAIRE

Indoor Air Quality Questionnaire

General House Information

1. What is the zip code of your primary residence? _____

2. Upon what type of foundation is your primary residence constructed (check all that apply)?
   - o Basement
   - o Crawl-space
   - o Slab-on-grade
   - o Don't Know

3. If you have a Basement, is it finished?
   - o Yes – mostly
   - o Yes – partially
   - o No

4. How many bedrooms does your home have? _____

5. How much of your home is carpeted? (check the most appropriate answers in the table below)

	25% or less	26-49%	50-74%	Over 75%	N/A
First Floor	❍	❍	❍	❍	❍
Second Floor	❍	❍	❍	❍	❍
Third Floor	❍	❍	❍	❍	❍
Basement	❍	❍	❍	❍	❍

6. Do you have an attached garage (check all that apply)?
   - o Yes – Directly connected to living space by a common wall
   - o Yes - Directly connected to living space above garage
   - o No

7. Are there any fireplaces/heating stoves in the home? (check all that apply)
   - o Yes- WOOD burning
   - o Yes- vent-free GAS logs/stoves/fireplaces
   - o Yes- vented to outside-GAS logs/stoves/fireplaces
   - o Yes- other (pellet, coal, etc.)
   - o No

8. If you have a fireplace/heating stove in your hope, how are the combustion gasses vented? (check all that apply)
    - o Natural draft
    - o Mechanically ventilated flue
    - o Ventless (appliance is not vented to the outside or is considered vent-free)
    - o Don't know

9. What type fuel/energy does the water heater use?
    - o Electricity
    - o Natural or LP Gas
    - o Oil
    - o Don't know

10. What type of heating system does your house have (if multiple systems, check primary equipment)?
    - o Forced-air furnace
    - o Electric Baseboard
    - o Heat Pump
    - o Hydronic heat- Hot water/steam with a boiler (radiant floor, baseboard, steam) check fuel type
    - o Other (describe)_____
    - o Don't know

11. What is the PRIMARY fuel/energy type used to heat your home? (check only one)
    - o Natural Gas
    - o LP (or bottled gas)
    - o Oil
    - o Electricity
    - o Wood/Coal
    - o Other (describe)_____
    - o Don't Know

12. What type of cooling system(s) do you use? (check all that apply)
    - o Central Air Conditioning or Heat Pump
    - o Window/wall AC unit(s) for just one or two rooms
    - o Window/wall AC unit(s) enough to cool the entire house
    - o Evaporative cooling system – (more common in dry climates)
    - o Fans – Either whole house, window or room fans
    - o Other (describe)_____
    - o No Air Conditioning

13. Does your home have automatic ventilation designed to bring in fresh air? (excludes manually operated fans- e.g. bath fan, range hoods, etc.)
    - o Yes- Heat/Energy Recovery Ventilators (HRV/ERV)
    - o Yes- Continuously-timed or Humidity based
    - o Yes- Other _____
    - o Yes- Don't know type
    - o No
    - o Don't Know

14. Which rooms have exhaust fans vented to the outside? (check all that apply)

	Fan vented to outside	Re-circulating fan	No Fan	N/A	Don't Know
Kitchen	❍	❍	❍		❍
Bath w/shower or tub	❍		❍		❍
Powder Room (1/2 Bath)	❍		❍	❍	❍

15. Have you ever noticed condensation forming (sweating) on or in:

Location	***Daily***	***Occasionally***	***Only in Winter***	***Only in Summer***	***Never***
Bathroom					
Other Rooms					
Toilet Tank					
Windows (not in bathrooms)					

16. Is the general area (town or county) known for high levels of RADON?
    - o Yes
    - o No
    - o Don't know

17. Has your home ever been tested for RADON?
    - o Yes – level was considered high
    - o Yes – level was considered acceptable
    - o Yes – don't know level
    - o No
    - o Don't know

18. Does your home have a humidifier that is used?
    - o Yes – Portable
    - o Yes- Integrated into central air heating system
    - o No
    - o Don't Know

19. Does your home have a dehumidifier that is used?
    - o Yes- Portable
    - o Yes- Integrated into central air system
    - o No
    - o Don't Know

Lifestyles

20. What is the temperature inside the house when occupied?
    Winter Day _____F Night ____F
    Summer Day_____F Night _____F (leave blank if no air conditioner)

21. Does anyone smoke inside the primary residence?
    - o Yes
    - o No

22. How many of the following kinds of pets live in your house?
a) Dogs _____
b) Cats _____
c) Birds _____
d) Other fur-covered pets _____

23. How many plants do you keep inside your house?
    (for counting purposes, just provide the number of pots with plants)

    - o Number of pots ____

24. How often do you open windows for fresh air?

	Whenever Possible	Often	Seldom	Never
Summer	❍	❍	❍	❍
Fall	❍	❍	❍	❍
Winter	❍	❍	❍	❍
Spring	❍	❍	❍	❍

25. How many showers or baths are taken per day in the house?
    - o Less than 1
    - o 1- 2
    - o 3-5

- o 6 or more

26. How frequently is the bathroom fan used when showering or bathing?
    - o less than 50%
    - o more than 50%
    - o fan is automatic
    - o no fan installed

27. How often is wet laundry (or other) hung to dry indoors?
    - o never
    - o less than once per week
    - o more than once per week

28. If you have an attached garage (not a carport), how often to you park your vehicles inside it?
    - o My primary residence does not have an attached garage
    - o Almost everyday – Year round
    - o I store a vehicle inside but seldom use this vehicle
    - o Sometimes
    - o Only in winter
    - o Seldom/Never

29. How often do you change/clean your HVAC's air filter?
    - o Over 9 times per year
    - o 6-9 times per year
    - o 2-5 times per year
    - o 1 or fewer times per year
    - o My HVAC system does not have an air filter
    - o Don't know

30. What type of air-filter do you use? (check all that apply)
    - o Fiberglass, synthetic or stainless steel mesh air filter
    - o 1" Standard Efficiency Pleated Air Filter – (MERV 4-6)
    - o High Efficiency/HEPA air-filter- (MERV 7-16)
    - o Electrostatic or electronic air-filter
    - o Stand Alone room air-purifiers
    - o Ozone/Ion Generator
    - o Other _____
    - o Don't know

Occupant Perceived Indoor Air Quality

31. Do you think any part of your home has problems with indoor air quality? (i.e.- musty smell in basement)

- o Yes
- o No

32. Whether or not you have problems with indoor air quality in your home, how would you rate the quality of the air you breathe inside your home?

- o Very poor
- o Poor
- o Neutral
- o Good
- o Very good

33. When you are inside your home, what are your ratings concerning the following conditions during winter and during the summer throughout most of the house?

	Winter					Summer				
General Comfort	Un-comfortable				Comfortable	Un-comfortable				Comfortable
	1	2	3	4	5	1	2	3	4	5
Air	Stale				Fresh	Stale				Fresh
	1	2	3	4	5	1	2	3	4	5
Odors	Lingers				Dissipates Quickly	Lingers				Dissipates Quickly
	1	2	3	4	5	1	2	3	4	5
Humidity	Damp/Musty				Dry	Damp/Musty				Dry
	1	2	3	4	5	1	2	3	4	5
Air Movement	Drafty/ Stagnant				Comfortable	Drafty/ Stagnant				Comfortable
	1	2	3	4	5	1	2	3	4	5
Dust	Dusty				Clean	Dusty				Clean
	1	2	3	4	5	1	2	3	4	5
Air Quality	Poor				Good	Poor				Good
	1	2	3	4	5	1	2	3	4	5
Temperature	Chilly				Cozy	Hot				Cool
	1	2	3	4	5	1	2	3	4	5

34. Has visible mold been present anytime within the last five years in the home? (check all that apply)

- o Yes- in Bathroom/Kitchen
- o Yes- In Basement
- o Yes- In other rooms
- o No

35. Have you ever noticed a musty smell in the following locations (check all that apply)
    - o bedroom
    - o bath
    - o basement
    - o crawl space
    - o attic
    - o kitchen
    - o living room
    - o den
    - o attached garage

36. Has there been any water related problems in the house within the last 5 years? (check all that apply)
    - o Yes- broken/leaky water pipes
      how long did it persist (days, weeks. Months)
    - o Yes- ground water leak in basement or lowest level of home
      How frequently does this occur (one time occurrence, annual or less frequent, seasonal, ongoing)
    - o Yes- overflowing sink/toilet/shower/tub/appliance
      How frequently does this occur (weekly, monthly, yearly)
    - o Yes- leaky roof/window/door
      how long did it persist (days, weeks. Months)
    - o Yes- other
    - o No
    - o Don't know

37. In general, how do you rate the day-to-day comfort provided by your home's heating and or air conditioning system?

	Very Poor	Poor	Neutral	Good	Very Good
Heating season	❍	❍	❍	❍	❍
Cooling season	❍	❍	❍	❍	❍

Health Conditions

38. Do you think that a home's indoor air quality has any impact on the health of its occupants?
    - o Yes
    - o No
    - o Maybe
    - o Don't Know

39. How often have each of the following symptoms occurred in your household during the past year?

Check the boxes if you believe that these symptoms are related to indoor air quality.

	Daily	Weekly	Monthly	Seasonal Summer/ Fall	Seasonal Winter/ Spring	Rarely /Never
Headaches	❍	❍	❍	❍	❍	❍
Hay Fever	❍	❍	❍	❍	❍	❍
Skin rashes	❍	❍	❍	❍	❍	❍
Nose bleeds	❍	❍	❍	❍	❍	❍
Common Colds	❍	❍	❍	❍	❍	❍
Asthma (physician diagnosed)	❍	❍	❍	❍	❍	❍

Interest in Future House and Indoor Air Testing

The next phase of this study, will involve air quality testing some of the houses involved in the survey. Tests could range from a one-time visit that would take about an hour, up to extended monitoring that could go beyond six months. Your level of participation will be completely at your discretion and all results will be made available to you at no cost. No houses in the study will be identified by owner or address. Testing is only being conducted for the purpose of research and there will be absolutely no sales solicitations.

40. Would you be willing to participate at some level in the next phase of this study
    - Yes - If your home is selected, we will contact you and provide additional details at that time (regarding the process and procedure after which you) will have the option to either accept or decline an actual visit.
    - No