*** Provisional Draft***

# ASSESSING ALLERGENS AND ASTHMA TRIGGERS IN THE HOME ENVIRONMENT: A STUDY OF THE SOUTHEASTERN UNITED STATES

**Final Report**

Prepared for:

U.S. Department of Housing and Urban Development

Office of Healthy Homes and Lead Hazard Control

Prepared by:

Brack W. Hale, Ph.D.

Marie Lynn Miranda, Ph.D.

Children's Environmental Health Initiative
A Research and Community Outreach Program of the
Nicholas School of the Environment and Earth Sciences at Duke University

HUD Grant No.NCLHH0096-01

Duke University

Durham, NC

29 December 2005

***Provisional Draft***

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following individuals for their contributions in preparing and reviewing this report: Anna Bauer, Jeffrey Davis, Tracy Dixon (of Advanced Energy), Susan Herst, Christopher Paul, Matthew Stiegel, Wayne Thomann, and Joshua Tootoo.

**HUD Government Technical Representatives: Allan Daly, Robert F. Weisberg, Ph.D.**

Visit the OHHLHC Web Site www.hud.gov/offices/lead to find this report and others posted by HUD's Office of Healthy Homes and Lead Hazard Control

*****Provisional Draft*****

ABSTRACT

This project was designed to assess allergens and asthma triggers in the indoor home environment. Because the Southeast has been the subject of relatively little research on indoor environmental health issues, despite having a climate very favorable to the growth and persistence of molds, dust mites, and cockroaches, the project focused on six counties in North Carolina. It included field sampling in homes to measure levels of allergen and asthma triggers. The project then integrated the results of the sampling into a Geographic Information System (GIS) to develop models that associated risk factors with the presence of allergens and asthma triggers in the home environment. Concurrently, CEHI worked with community partners, government agencies, and other interest groups to educate the public about home environmental health risks and disseminate project findings. In order to help local communities strengthen their own capacity to operate sustainable, preventive programs that address housing-based hazards, residents and community organizations and institutions needed good information about the risks and contributing factors specific to their locale. The project uncovered key insights regarding respiratory health threats in the home environment, which can in turn be used to tailor and prioritize intervention programs.

***Provisional Draft***

THIS PAGE INTENTIONALLY LEFT BLANK

## TABLE OF CONTENTS

TABLE OF CONTENTS ..... I
LIST OF TABLES ..... III
LIST OF FIGURES ..... III
EXECUTIVE SUMMARY ..... VI
BIOAEROSOLS IN THE HOME ..... VII
DUSTBORNE ALLERGENS IN THE HOME ..... VII
COMBINED ALLERGEN LOADS IN HOMES ..... VII
ROLE OF CRAWLSPACE ..... VII
1.0 INTRODUCTION ..... 9
1.1 GRANT OVERVIEW ..... 9
1.1.1 GOALS ..... 10
1.1.2 RESULTS ..... 10
2.0 GRANT ACTIVITIES ..... 11
2.1 ASSESSMENT OF ORIGINAL WORK PLAN ..... 11
2.2 SCHEDULE ..... 11
2.3 CHRONOLOGY OF GRANT MODIFICATIONS ..... 12
2.4 GRANT ACCOMPLISHMENTS ..... 13
2.5 UNITS COMPLETED ..... 13
2.6 TASK AND ACTIVITY ASSESSMENT ..... 14
2.6.1 ORIGINAL AWARD ..... 14
2.6.2 CRAWLSPACE AMENDMENT ..... 15
2.7 APPENDIX—SAMPLE SAMPLING REPORT ..... 16
3.0 EDUCATION AND OUTREACH ..... 20
3.1 PARTICIPANT EDUCATION AND OUTREACH ..... 20
3.2 LOCAL COMMUNITY EDUCATION AND OUTREACH ..... 24
3.3 APPENDIX I: MANUSCRIPT SUBMISSION ..... 28
3.4 APPENDIX II: LISTING OF INFORMATION DISSEMINATION ..... 28
3.5 LEAD HAZARD AND POISONING OUTREACH WORK WITH COMMUNITY PARTNERS AGAINST LEAD ..... 33
4.0 RESEARCH FINDINGS ..... 35
4.1 GENERAL SAMPLING METHODOLOGY ..... 35
4.1.1 BIOAEROSOL SAMPLING METHODOLOGY ..... 35
4.1.2 BULK DUST SAMPLING METHODOLOGY ..... 37
4.2 SEASONAL VARIATION IN INDOOR BIOAEROSOLS ..... 37
4.2.1 METHODS AND ANALYSIS ..... 37
4.2.2 RESULTS ..... 38
4.2.3 SIGNIFICANCE ..... 42
4.3 BIOAEROSOLS IN THE HOME ENVIRONMENT ..... 44
4.3.1 BIOAEROSOL SAMPLING METHODOLOGY ..... 44
4.3.2 FINDINGS ..... 44
4.4 BULK DUST ALLERGENS IN THE HOME ENVIRONMENT ..... 55
4.4.1 BULK DUST SAMPLING METHODOLOGY ..... 55
4.4.2 FINDINGS ..... 55
4.5 CO-OCCURRENCE OF BIOAEROSOLS AND BULK DUST ..... 61
4.5.1 METHODS AND ANALYSIS ..... 61
4.5.2 FINDINGS. ..... 61
4.6 CRAWLSPACE CHARACTERIZATION ..... 64

4.6.1 SAMPLING METHODOLOGY ....... 65
4.6.2 TRANSMISSION CLASSIFICATION. ....... 67
4.6.3 TRANSMISSION ASSESSMENT ....... 68
4.7 ANALYSIS OF NON-INVASIVE AND INVASIVE CRAWLSPACE SAMPLING ....... 72
4.7.1 METHODS ....... 72
4.7.2 FUNGAL COUNTS FINDINGS ....... 72
4.7.3 FUNGAL SAMPLE COMPOSITION ....... 73
4.8 ADVANCED ENERGY'S PHASE II ....... 76
4.8.1 CRAWLSPACE CHARACTERIZATION ....... 76
4.8.2 TEMPERATURE AND RELATIVE HUMIDITY STUDY ....... 79
4.9 EVALUATION OF FIRE RISKS ....... 81
4.9.1 PRESENCE OF SMOKE DETECTORS ....... 81
4.9.2 SMOKE DETECTOR FUNCTIONING ....... 82
5.0 CONCLUSIONS AND LESSONS LEARNED ....... 83
5.1 RESEARCH CONCLUSIONS ....... 83
5.1.1 BIOAEROSOLS IN THE HOME ....... 83
5.1.2 DUSTBORNE ALLERGENS IN THE HOME ....... 84
5.1.3 COMBINED ALLERGEN LOADS IN HOMES ....... 84
5.1.4 ROLE OF CRAWLSPACE ....... 84
5.1.5 FIRE RISKS IN THE HOME ....... 85
5.2 COMMUNITY OUTREACH AND EDUCATION ....... 85
6.0 FINANCIAL SUMMARY ....... 85
7.0 REFERENCES ....... 88

## LIST OF TABLES

Table 3-1. Outreach materials. .......... 21
Table 3-2a. Durham County points of contact for participant education and outreach. .......... 23
Table 3-2b. New Hanover County points of contact for participant education and outreach. .......... 23
Table 3-2c. Wilson County points of contact for participant education and outreach. .......... 23
Table 3-3. Presentations. .......... 24
Table 3-4. Collaborating community agencies. .......... 25
Table 4-1. Bioaerosol sample codes. .......... 36
Table 4-2. Mean relative humidity and temperature across sampling locations and seasons (± standard error). All values differ significantly across seasons, p<0.001. .......... 38
Table 4-3. Summary measures of fungal counts across seasons (CFU/$m^3$) and results of Wilcoxon signed rank test. .......... 40
Table 4-4. Spearman rank correlation of indoor and outdoor fungal counts across seasons. .......... 42
Table 4-5. Spearman rank correlation of indoor and outdoor fungal counts across seasons. .......... 42
Table 4-6. Significant variables in the bioaerosol models. .......... 49
Table 4-7. Coefficients of significant environmental factors associated with fungal counts in the home environment (Figures in *italics* had a p-value between 0.05 and 0.10). .......... 50
Table 4-8. Coefficients from abundance models, reflecting effect of sampling year on indoor bioaerosol levels. .......... 52
Table 4-9a. Coefficients of significant demographic and household factors associated with fungal counts in home environment (Figures in italics had a p-value between 0.05 and 0.10). .......... 53
Table 4-10. Basis for bioaerosol flags. .......... 54
Table 4-11. Coefficients of factors associated with indoor bioaerosol flags .......... 54
Table 4-12. Criteria for flags for bulk dust allergens. .......... 55
Table 4-13. Significant variables in allergen models. .......... 57
Table 4-14. Coefficients for environmental and demographic factors associated with indoor dust allergen levels .......... 58
Table 4-15. Coefficients for sampling year. .......... 59
Table 4-16. Coefficients for house-level factors associated with indoor dust allergen levels .......... 60
Table 4-17. Odds ratios for factors related to BD flags. .......... 61
Table 4-18. Co-occurrence of bioaerosol and bulk dust problems in sample homes. .......... 62
Table 4-19. Logistic regression for co-occurrence of BA and BD flags. .......... 64
Table 4-20. Bioaerosol sample codes. .......... 66
Table 4-21. Distribution of homes across transmission categories for 5- and 8-sample homes. .......... 68
Table 4-22. Comparison of I1 and I3 for 5-sample homes using the Wilcoxon matched-pairs signed rank test. .......... 69
Table 4-25: Factors associated with having smoke detectors. [n=654; LR $chi^2$ (4) = 19.47, p=0.0006, pseudo $r^2$ = 0.080] .......... 82
Table 4-26: Factors associated with having functioning smoke detectors. [n=644; LR $chi^2$ (3) = 30.53, p=0.0000, pseudo $r^2$ = 0.047] .......... 83

## LIST OF FIGURES

Figure 1-1: Study locations in North Carolina .......... 9
Figure 2-1: Sampling effort by month .......... 12
Figure 3-1. Outreach benchmarks .......... 27
Figure 3-2. Skills training benchmarks .......... 27
Figure 4-1. Non-invasive crawlspace sampling (CS1) .......... 36

Figure 4-2. Diffuser sampling (Diff1 and Diff2)....................36
Figure 4-3. The Boss Mighty Might" vacuum ....................37
Figure 4-4a. Detection frequency in outdoor samples by season....................39
Figure 4-4b. Detection frequency in indoor samples ....................39
Figure 4-5. Median composition of outdoor fungal community across seasons (NB: Both *Aspergillus* median values were zero and thus left off the figure; the distributions did differ significantly across seasons, p=0.02). Columns with different letters differ significantly, p< 0.05. ....................41
Figure 4-6. Composition of indoor fungal community across seasons (NB: *Aspergillus* was left out as its median values were zero; the distributions did not differ significantly across seasons, p>0.1). Columns with different letters differ significantly, p< 0.05....................41
Figure 4-7. Geometric mean of total fungal count by region (columns with different letters represent significant differences across region, p ≤ 0.05). ....................45
Figure 4-8. Average percent *Cladosporium* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05)....................45
Figure 4-9. Average percent *Penicillium* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05)....................46
Figure 4-10. Average percent *Mycelia sterilia* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05)....................46
Figure 4-11. Average percent Other species in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05)....................47
Figure 4-12. Detection frequency of *Aspergillus* by region. ....................47
Figure 4-13. Mean percent land cover within 500 m radius of home. Different letters indicate significant differences (p < 0.05) across regions for individual land cover types. ....................48
Figure 4-14a. Relationship between total indoor fungal count (CFU/m$^3$) by land cover and distance to floodplain in Durham County, NC. ....................50
Figure 4-14b. Relationship between total indoor fungal count (CFU/m$^3$) by land cover and distance to floodplain in New Hanover County, NC. ....................51
Figure 4-15. Average temperature and precipitation for Eastern and Central NC during sampling season by sampling year (source: NWS data). ....................52
Figure 4-16. Prevalence of bioaerosol flags by region....................54
Figure 4-17a. Geometric mean of allergen levels across regions....................56
Figure 4-17b. Median allergen levels by region ....................56
Figure 4-18a. Relationship of Der f1 levels to selected environmental and demographic variables in Wilson County, NC. ....................58
Figure 4-18b. Relationship of Der p1 levels to selected environmental and demographic variables in Wilson County, NC. ....................59
Figure 4-19. Causes for BD flags....................60
Figure 4-20. Distribution of bioaerosol (BA), bulk dust allergen (BD) and joint (BABD) flags across geographic regions....................62
Figure 4-21. Underlying causes for BABD flags across regions. ....................63
Figure 4-22. Simplified layout of a HVAC system in a crawlspace. Blue plus sign indicates location of indoor samples; red star indicates location of the diffuser samples (Diff1 and Diff2).65
Figure 4-23: Non-invasive sampler used in study....................66
Figure 4-24. Median sample fungal counts for 5-sample homes. ....................67
Figure 4-25. Median sample fungal counts for 8-sample homes. ....................68
Figure 4-26. Mean indoor sample fungal counts by transmission category. (columns with different letters represent significant differences across samples, p<0.017). ....................70
Figure 4-27. Comparison of mean fungal counts in crawlspace samples by transmission category (columns with different letters represent significant differences across samples, p<0.05)....................71

Figure 4-28. Comparison of mean fungal counts in diffuser samples by transmission category 71
Figure 4-29. Geometric mean of total airborne fungal levels in crawlspace by sampling method. ........ 72
Figure 4-30. Geometric mean of total airborne fungal levels in indoor and diffuser samples, by sampling method........ 73
Figure 4-31. Median fungal group proportions in crawlspace samples by sampling method..... 74
Figure 4-32. Median fungal group proportions in diffuser samples by sampling method........... 74
Figure 4-33. Median fungal group proportions in indoor samples by sampling metho.............. 75
Figure 4-44: Number of smoke detectors per home by region ........ 82
Figure 4-45: Mean percentage of functioning smoke detectors in homes with smoke detectors, by region. ........ 83

## EXECUTIVE SUMMARY

This report summarizes the activities and findings of two consecutive awards from the Department of Housing and Urban Development's Office of Healthy Homes and Lead Hazard Control: the original grant (NCLHH0096-01), awarded on 1 March 2002, and an amendment to the original grant, awarded on 23 June 2003.

Allergen and asthma triggers represent important health risks in the home environment, particularly for sensitive individuals and vulnerable populations, such as children. Molds, dust mites, and cockroaches are some of the major triggers commonly found in homes that influence respiratory outcomes. Through this Healthy Homes Technical grant, Duke University improved the understanding of both the distribution and the environmental, demographic, and social factors associated with these allergens and asthma triggers in homes in North Carolina. This area, and indeed, the entire Southeast has been the subject of relatively little research on indoor environmental health issues, despite having a climate very favorable to the growth and persistence of molds, dust mites, and cockroaches. The project focused and built upon and contributed to the Children's Environmental Health Initiative's (CEHI) existing Geographic Information System (GIS) of environmental, demographic, and socioeconomic variables in the study area.

To address the goals of the Healthy Homes Initiative, our initial project included four objectives:

1. Expand CEHI's GIS to include publicly available data relevant to the study of allergens and asthma triggers;
2. Conduct in-home assessments in 300 homes to measure levels of dustborne and airborne (bioaerosol) allergens and asthma triggers;
3. Develop models to predict the occurrence of the allergens and asthma triggers;
4. Disseminate the findings to the participants, relevant government agencies, and community groups, as well as the lay public;

Upon receiving the amendment to investigate the crawlspace environment, we added the following objectives to our study plan:

5. Sample bioaerosols in 125-150 homes with crawlspaces;
6. In a subset of 40-50 homes, conduct long-term sampling of the crawlspace environment, including temperature and relative humidity;
7. Statistically evaluate the relative contribution of crawlspaces to mold species in the livable part of the home environment, as well as potential causes for transmission.

**Accomplishments**

We sampled in a total of 955 homes in six counties in North Carolina (Chatham, Durham, New Hanover, Orange, Wayne, and Wilson), including 228 in our pilot project prior to HUD funding. Of these homes, we sampled in 187 homes for the first phase of crawlspace sampling, and 46 homes for the second phase. We sent all participants detailed sampling reports that outlined our findings and what they meant and included follow-up educational materials. CEHI outreach efforts exceeded benchmark expectations in both outreach events and meetings, and skills training events. CEHI participated in 75 meetings and events during the period of the project, based on tallies of official community events and regularly held meetings. This does not reflect the entire scope of inter-organizational contacts common in CEHI's partnerships. CEHI's goal was to have ten training events to promote its training themes of using GIS as a tool, GIS capacity building, and improving data management; in fact, we held eighteen events. We have disseminated our findings in many venues, including oral and poster presentations and have developed multiple manuscripts submitted to peer-reviewed journals.

**Findings**

### *Bioaerosols in the Home*

Our research revealed that indoor bioaerosol loads are strongly correlated with outdoor levels, regardless of air conditioning usage. Coastal areas appear to have lower overall fungal levels, but different fungal compositions compared to the Coastal Plain and the Piedmont. At the home level, forested land cover near homes can increase local fungal loads. Newer homes tend to have lower fungal loads, while homes with crawlspaces tend to have higher loads. Overall, more than half of the homes sampled experience some type of bioaerosol problem. We found that homes are less likely to have bioaerosol problems during drought periods, in areas lacking significant forest cover, in agricultural areas, and if the home does not have a crawlspace.

### *Dustborne Allergens in the Home*

Our investigations into dustborne allergens found that dust mite allergens (Der p1 and Der f1) are much more common than cockroach allergens in our study area. Levels of Der p1 allergens are higher in homes closer to forested areas and farther from agriculture. They are also higher in areas of higher incomes, in homes that are partially carpeted and in older homes. In contrast, levels of the Der f1 allergen did not show significant seasonal variation, but are higher in homes closer to forested areas. They are also higher in areas of higher median incomes and newer homes. Detection of the Bla g1 allergen was relatively infrequent in our study area and tended to occur more frequently in areas with newer homes, more renter-occupied housing, a higher proportion of Hispanics, and in homes where residents either garden or work in the agricultural industry. Almost 80% of our sampled homes had problems with at least one of these three allergens, with the two dust mite allergens responsible for the vast majority of these homes. Homes were at higher risk for dustborne allergen problems if they are in an urban area or are fully carpeted. Conversely, homes further from forested areas, as well as renter-occupied homes tend to be at lower risk for problems with dustborne allergen levels.

### *Combined Allergen Loads in Homes*

Analyzing the bioaerosol and dustborne allergen data jointly revealed that a majority of homes have problems with both air and dustborne allergens. Homes were at higher risk for problematic BABD levels, if they were located in forested areas or if they were older homes. Conversely, cat or dog ownership or renter-occupied homes seem to be less likely to encounter problematic BABD levels. Our results did not suggest any disproportionate impact for homes in low income or high minority areas.

### *Role of Crawlspace*

As suggested in our initial bioaerosol findings, we found that crawlspaces can have a strong, often negative, influence on indoor air quality. This occurs because the temperature and humidity levels in crawlspaces generally provide an excellent environment for fungal growth. Human, animal, and weather-related disturbances of the crawlspace may then stir up fungal spores, thus facilitating their transmission into the home environment. Transmission occurs both through leaks between the home and the crawlspace, as well as via the HVAC system. Our sub-grantee, Advanced Energy, documented leaks between the crawlspace and the home interior in approximately 2/3 of the homes they investigated.

*Fire Risk in the Home Environment*

In this study, we found that blockgroup household median was the best predictor of the presence of smoke detectors in the home; wealthier areas were more likely to have homes with smoke detectors. Homes in newer neighborhoods were slightly more likely to have functioning smoke detectors, while Spanish-speaking homes were less likely to have functioning smoke detectors. This latter finding emphasizes the need for outreach and education to the growing Hispanic community in NC.

*Community Outreach and Education*

Studies such as this present many opportunities to conduct outreach and education to individuals and communities. We found that maintaining the flexibility to have individual and community level outreach activities enhances one's ability to connect with a target population. It was also our experience that outreach, education, and training are most effective if delivered or negotiated through a network of partnerships that have developed over time and if they respect community expertise and needs. Similarly, when participating in community events, developing relationships with community partners where they are treated as equal collaborators, rather than subjects, is crucial to gaining credibility with communities. We found it was important to include a diverse range of stakeholders into one's set of partners is important for leveraging multiple resources for outreach, education, and training. Lastly, in this project, leveraging resources across the Nicholas School of the Environment and Earth Sciences, the Division of Occupational and Environmental Medicine (OEM) within the Duke University Medical Center, and community partners provided an effective means to study and affect local environmental health risks.

# 1.0 INTRODUCTION

## 1.1 Grant Overview

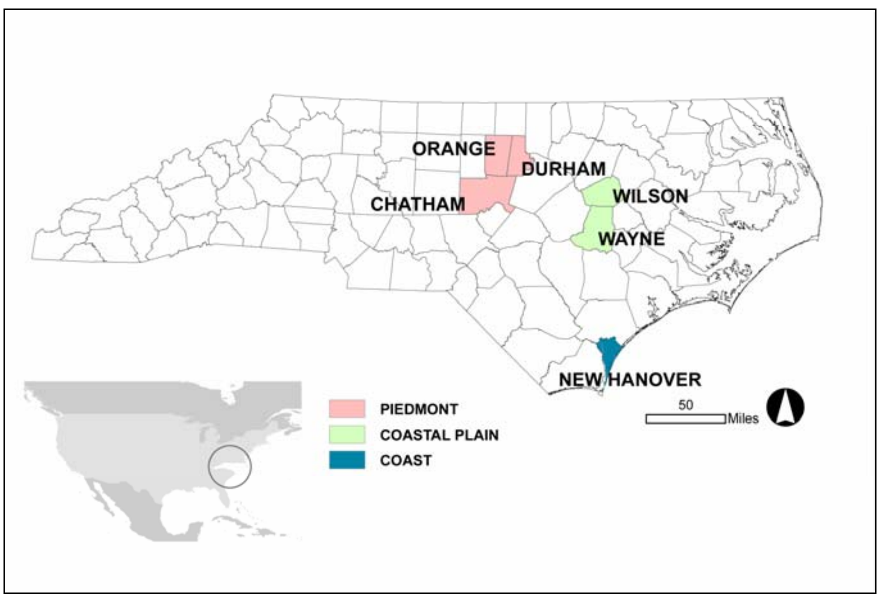
This report summarizes the activities and findings of two consecutive awards from the Department of Housing and Urban Development's Office of Healthy Homes and Lead Hazard Control: the original grant (NCLHH0096-01), awarded on 1 March 2002, and an amendment to the original grant, awarded on 23 June 2003.

The original project sought to answer two questions:

- Can sophisticated information management technologies generate predictive models for childhood allergen and asthma trigger exposures?
- Does the relationship between a predictive model for childhood allergens, asthma triggers, and fire risks and a predictive model for childhood lead exposure risks demonstrate a potential for enhanced resource utilization by combining environmental intervention strategies?

The project focused on six counties in North Carolina and built upon and contributed to the Children's Environmental Health Initiative's (CEHI) existing Geographic Information System (GIS) of environmental, demographic, and socioeconomic variables in the study area (**Figure 1-1**). It included field sampling in homes in the study area to measure levels of allergen and asthma triggers. The project then integrated the results of the sampling into the GIS to develop models that associated risk factors with the presence of allergens and asthma triggers in the home environment. Concurrently, CEHI worked with community partners, government agencies, and other interest groups to educate the public about these risks and disseminate project findings.

**Figure 1-1: Study locations in North Carolina**




As our research progressed, we developed a growing concern about the influence that crawlspaces may have on allergens and asthma triggers in the home environment. The amendment to the original award allowed us to investigate the importance of crawlspaces as reservoirs for mold transported into the livable part of the home environment. The amendment to the original award was carried out in two phases. The first phase was executed by CEHI to examine the general relationship of crawlspace and indoor airborne fungal levels and the possible role of the HVAC system as a conduit for fungal transmission. The second phase was executed by a sub-contractor, Advanced Energy, and more closely examined a subset of the homes sampled in the first phase. Both phases of the crawlspace study included public outreach and education components.

#### *1.1.1 Goals*

This project strove to address each of the overall goals and objectives of the Healthy Homes Initiative. The project sought to foster private and public cooperation by leveraging the resources and technical expertise of CEHI and the Division of Occupational and Environmental Medicine (OEM) within the Duke University Medical Center for use beyond the academy in the broader community. The project also strove to build on established relationships between CEHI and public health institutions and locally-based community organizations.

In order to help local communities strengthen their own capacity to operate sustainable, preventive programs that address housing-based hazards, residents and community organizations and institutions needed good information about the risks and contributing factors specific to their locale. The project sought to enable local communities to tailor intervention programs to their specific areas. In addition, the project sought to address risk disparities and, in turn, prioritize intervention strategies. Fair housing must be safe for everyone; this project aimed to provide both the public and private sectors with the information needed to address respiratory health threats in the home environment.

To address the goals of the Healthy Homes Initiative, our initial project included major objectives:

1) Expand CEHI's GIS to include publicly available data relevant to the study of allergens and asthma triggers;
2) Conduct in-home assessments in 300 homes to measure levels of dustborne and airborne (bioaerosol) allergens and asthma triggers and other home health risk factors;
3) Develop models to predict the occurrence of the allergens and asthma triggers, as well as fire risks;
4) Disseminate the findings to the participants, relevant government agencies, and community groups, as well as the lay public;

Upon receiving the amendment to investigate the crawlspace environment, we added the following objectives to our study plan:

5) Sample bioaerosols in 125-150 homes with crawlspaces;
6) In a subset of 40-50 homes, conduct long-term sampling of the crawlspace environment, including temperature and relative humidity;
7) Statistically evaluate the relative contribution of crawlspaces to mold species in the livable part of the home environment, as well as potential causes for transmission.

#### *1.1.2 Results*

We were very successful in meeting our goals. We developed a GIS that contains relevant information layers from tax parcel, US Census (block and block group level demographics), land cover and land use, hydrography, and sampling and survey data. We sampled in a total of 955 homes, including 228 in our pilot project prior to HUD funding. Of these homes, we sampled in 187 homes for the first phase of crawlspace sampling, and 46 homes for the second phase. We sent all participants detailed sampling reports that outlined our findings and what they meant and included follow-up educational materials. CEHI outreach efforts exceeded benchmark expectations in both outreach events and meetings, and skills training events. CEHI participated in 75 meetings and events during the period of the project, based on tallies of official community events and regularly held meetings. This does not reflect the entire scope of inter-organizational contacts common in CEHI's partnerships. CEHI's goal was to have ten training events to promote its training themes of using GIS as a tool, GIS capacity building, and improving data management; in fact, we held eighteen events. We have disseminated our findings in many venues, including oral and poster presentations at the 2002 CDC-sponsored conference, "Living Well with Asthma" in Atlanta, at the 2004 Healthy Homes Grantee Conference in Orlando, and at 2004 and 2005 American Public Health Association (APHA) meetings, in Washington DC and Philadelphia, respectively (see section 3.4 for more details). We also presented a technical seminar at the National Institute of Environmental Health Sciences (NIEHS) and a plenary address at a national conference on children's environmental health organized by the National Institutes of Health (NIH). Additionally, we have generated several manuscripts either already submitted or to be submitted to peer-reviewed journals.

# 2.0 GRANT ACTIVITIES

## 2.1 Assessment of Original Work Plan

Our original work plan proved to be very effective in achieving most of our goals. We were able to achieve the targeted sample size, although we encountered an unforeseeable delay due to weather conditions during two sampling seasons (see discussion below in section 2.4 and 2.5). Our plan for community outreach and education efforts was also very successful and allowed us to educate our study participants about home environmental health, as well as establish excellent relationships with community groups and government personnel. Our original recruitment plan needed refinement, due to the initial low-level of enrollment of minority and lower income participants (see discussion below in section 2.6). We addressed this problem by adjusting our recruitment strategies. Our original study required enhancement to adequately investigate the role that the crawlspace can play in indoor bioaerosol levels. Consequently, we sought and received an amendment to add this aspect to our study.

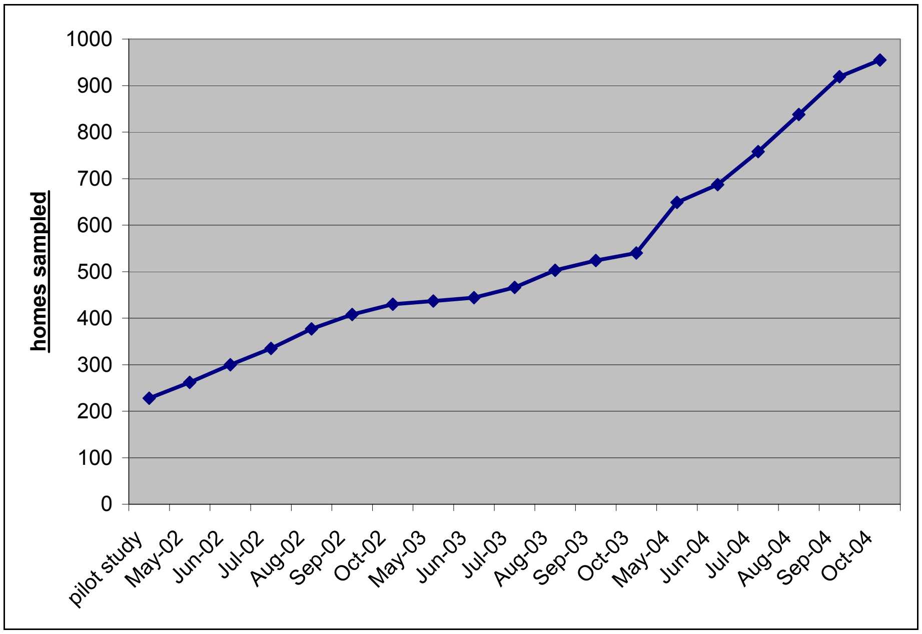
We altered our original study plan in the following ways:

1) Our initial grant application included sampling in Buncombe County, located in the Appalachian Mountains in western NC. Due to the high cost of running sampling in all regions of NC, we eliminated Buncombe County from our sampling sites and chose to focus on Central and Eastern NC.
2) We were able to obtain limited data on radon and asbestos in housing in NC. Unfortunately, the existing data was not extensive enough, nor did resources allow us to collect additional data, to have it fully incorporated into our modeling efforts.
3) As mentioned above, we sought an amendment of $333,332.00 to the original award of $405,217.00 to investigate the role the crawlspace plays with indoor bioaerosol levels. The costs associated with this amendment increased the total costs, expanded the number of units sampled, and extended the period of performance of the grant.

## 2.2 Schedule

The sampling aspect of our project ran into difficulties during the 2002 and 2003 sampling seasons. By its nature, our sampling was limited to the months of April through October. Central and Eastern NC suffered extreme drought during 2002 followed by heavy rainfall during the summer of 2003. These two weather events severely limited the feasibility of collecting home samples (**Figure 2-1**). As such, we needed to expand our sampling effort into 2004 in order to address the weather-related variability in the data from 2002 and 2003. This delayed our final data analysis and subsequent preparation of manuscripts for peer-reviewed journals. Despite this sampling challenge, our community education and outreach efforts continued unhindered. Further, the increase in our sampling efforts combined nicely with the amendment we received to investigate the role that crawlspaces play in indoor bioaerosol levels.

**Figure 2-1: Sampling effort by month**




## 2.3 Chronology of Grant Modifications

The original grant award of $405,217.00had a beginning date of March 01, 2002, an ending date of February 28th, 2004.

The first modification to the grant was Amendment 1, effective June 23rd, 2003. This amendment was an expansion of the original grant. In addition, the Statement of Work was modified to reflect the below changes, the period of performance was extended for an additional 17 months, and the total award was increased by an additional $333,332.00 in federal funds, with a matching contribution of $86,625.00 for a total increase of $419,957.00.

Also within Amendment 1, the Cover Page of HUD form 1004, block 9 was changed to read: "GTR, Emily Williams (202) 755-1785x127, GTM Joey Zhou, (202) 755-1785, x153." Block 14 was changed to read: "Previous HUD Amount $405,217.00, HUD Amount this action $333,332.00." Block 15a was changed with the following HUD Accounting and Appropriation Data: "Appropriation Number 86x0174 (LHH), $405,217.00, 862/30174 (LHH), $333,332.00." Block 15b was changed to read: "Reservation Number LHH02-11 (FY01), LHH03-13 (FY02)." Block 16 added: "Number of units to receive intervention: 120." Revisions to the Scope of Work included the Period of Performance which was changed to read: "The grantee shall provide all services hereunder for a period of 43 months from the effective date of the grant (03/01/2002 to 9/30/2005)."

Amendment 1, The BUDGET was changed to read as follows:

| Line Item | HUD Amount | Match Amount |
|---|---|---|
| 1. Personnel | $225,005.00 | $ 0.00 |
| 2. Fringe Benefits | $ 45,457.00 | $ 0.00 |
| 3. Travel | $ 16,227.00 | $ 0.00 |
| 4. Equipment | $ 0.00 | $ 0.00 |
| 5. Supplies | $ 34,000.00 | $56,250.00 |
| 6. Consultants | $ 0.00 | $ 0.00 |
| 7. Contracts | $120,000.00 | $ 0.00 |
| 8. Other | $ 72,200.00 | $ 0.00 |
| 9. Indirect Costs | $225,660.00 | $30,375.00 |
| 10.Totals | $738,549.00 | $86,625.00 |

The second modification to the grant was Amendment 2, effective June 23, 2003. This amendment was issued to correct the number of months in form 1044, Block 16 of Amendment 1 from: "….an additional 17 months …" to "….an additional 19 months…" and to change Block 9 to "GTR, Emily Williams, (336)547-4002".

## 2.4 Grant Accomplishments

We sampled in a total of 955 homes, including the 228 homes in our pilot project prior to HUD funding. This exceeded the combined goals of the grant and amendment by 277 homes. Of these homes, we sampled in 187 homes for the first phase of crawlspace sampling, and 46 homes for the second phase. We sent all participants detailed sampling reports that outlined our findings and what they meant and included follow-up educational materials. Additionally, we participated in 75 outreach events and conducted 18 training activities. We have given seven presentations at national and international conferences and have submitted or will submit a minimum of 6 manuscripts to peer-reviewed journals. Lastly, our sub-contractors on Phase II of the crawlspace amendment, Advanced Energy, generated two reports on their findings of long-term monitoring of the crawlspace environment.

The data collected during this project are stored on a private network located on-site in CEHI's offices at Duke University. Due to the sensitive nature of the data we collected, our IRB-approved protocol requires that we store the data in a secure manner to protect the anonymity of our study participants. To access the data, personnel must complete Duke University's Human Subjects Training and obtain permission from the project's P.I.'s, Drs. Miranda and Thomann.

## 2.5 Units Completed

We achieved the initial goal of 300 homes during the 2003 sampling season (**Figure 2-1**). Given the extreme weather conditions in years 2002 and 2003, we realized it would be necessary to increase the number of homes in our study to allow us to address the weather-related variation in our data adequately. The amendment to the original grant to investigate the role of crawlspaces dovetailed nicely onto our existing sampling program and simplified the collection of additional data. For the crawlspace amendment itself, we achieved our objective to enroll 150 Phase 1 crawlspace homes by September 2004 and exceeded it by 37 homes for a cumulative total of 187 sampled homes. For Phase 2 crawlspace sampling, we achieved our goal of enrolling at least 40 homes in October 2004 and exceeded it by 6 homes, for a total of 46 homes.

## 2.6 Task and Activity Assessment

### *2.6.1 Original Award*

With respect to the objectives laid out in the initial award, we achieved the following:

**1. Expand CEHI's GIS to include publicly available data relevant to the study of allergens and asthma triggers.**

Through this project, we expanded CEHI's existing GIS database to include land cover data, climatic data, hydrography, tax parcel data, socioeconomic data from the 2000 Census, in-home sampling data, and responses from the participant survey.

**2. Conduct in-home assessments in 300 homes to measure levels of dustborne and airborne (bioaerosol) allergens and asthma triggers and other home health risk factors.**

As reviewed in section 2.5, we assessed the original 300 plus 277 to account for unforeseen weather-related sampling difficulties.

**3. Develop models to predict the occurrence of the allergens and asthma triggers, as well as fire risks.**

We have thus far completed analyses of:

- seasonal variations in indoor fungal loads
- general levels in bioaerosol and dustborne allergens in the home environment
- the distribution of homes flagged for bioaerosol and dustborne allergen problems
- contributions of crawlspace construction to indoor bioaerosol levels
- the effectiveness of using a non-invasive crawlspace sampling technique developed by CEHI staff.

Additionally, we have modeled:

- environmental and socioeconomic factors related to the distribution of bioaerosol and dustborne allergens and asthma triggers in NC
- environmental and socioeconomic factors related to problem levels of both bioaerosol and dustborne allergens in the home
- the co-occurrence of bioaerosol and dustborne allergens and asthma triggers in the home
- demographic factors associated with elevated fire risks.

As more of our lead data comes in via our CDC-funded lead research, we will examine the co-occurrence of allergen and asthma triggers with biologically-available lead.

**4. Disseminate the findings to the participants, relevant government agencies, and community groups, as well as the lay public.**

We sent all participants detailed sampling reports that outlined and interpreted our findings. It also included follow-up educational materials (see section 2.7 for sample participant report). Additionally, we participated in 75 outreach events and conducted 18 training activities for community groups and government agencies. We have given seven presentations at national and international conferences (see section 3.4 for more details) and have submitted or will submit a minimum of 6 manuscripts to peer-reviewed journals from this part of the project.

In addition to the previously described weather-related sampling problem, we also encountered problems recruiting participants from minority groups and low-income populations. Our original plan only targeted these groups though poster-based recruitment targeted at local community groups and churches. We supplemented these efforts through door-to-door recruitment, as well as through visits with community groups and churches. These approaches significantly improved our recruitment of low income and minority participants and yielded balanced study demographics in the end.

### *2.6.2 Crawlspace Amendment*

With respect to the objectives laid out in the amendment, we achieved the following accomplishments:

5. **Sample bioaerosols in 125-150 homes with crawlspaces.**

   We sampled in 187 homes using a specialized protocol designed to elicit the contribution of the crawlspace to the presence of mold in the livable part of the home environment.

6. **In a subset of 40-50 homes, conduct long-term sampling of the crawlspace environment, including temperature and relative humidity**

   Our sub-grantee, Advanced Energy, sampled in 46 homes.

7. **Statistically evaluate the relative contribution of crawlspaces to mold species in the livable part of the home environment, as well as potential causes for transmission.**

   We completed these analyses and present the results in section 4.5.

We encountered no major problems in the implementation of the two phases of the project.

## 2.7 Appendix—Sample sampling report

**Allergen, Asthma, and Fire Risks Sampling Report**

Principal Investigators:
Marie Lynn Miranda, Ph.D, Duke University
Wayne Thomann, Dr. P.H., Duke University Medical Center

Nicholas School of the Environment and Earth Sciences
Children's Environmental Health Initiative (CEHI)

**INTRODUCTION**

Because adults and children today spend increasing amounts of time indoors, home environmental health is important for people's well being. Three important home environmental health issues include allergens, asthma triggers, and fire risks.

The number of people with asthma and allergies is increasing across the United States and in North Carolina. Asthma occurs as a result of repeated inflammation of the airways. If untreated or poorly managed, asthma results in coughing, wheezing, and breathing difficulty, and can result in death. It is the most common reason for missed school days. One risk factor for asthma is exposure to environmental allergens, including indoor and outdoor pollutants. Some of these pollutants include dust mite allergens, pet dander, cockroach allergens, mold spores, environmental tobacco smoke, and ozone. Dampness and high relative humidity can intensify mite infestation. Houses in the floodplain are also at risk for damp conditions, which may enhance fungal growth and exposure to mold and other allergens.

North Carolina's fire mortality rate is 2.8 deaths per 100,000, the eighth highest in the country. Fire fatalities often occur in residences lacking operational smoke detectors. In the southeast, fire-related deaths are connected to poorly maintained housing and the use of unvented and poorly maintained heating equipment. In North Carolina, mobile homes, rental units, and older homes pose increased risk for fire hazards.

The remainder of the report includes findings specific to your home. If you have any questions or comments, please feel free to contact CEHI at our toll free number 1-866-264-7891.

## IDENTIFYING INFORMATION

Visit Date: August 3, 2004
Report Date: October 27, 2004
Home Address: XXXXXXXXXXX, Durham, NC 277XX
Current Resident: John and Jane Doe

## SUMMARY

On August 3, 2004, field technicians from Duke University collected air and dust samples from the residence located at XXXXXXXXXX, Durham, NC 27707. The sampling was undertaken as part of a research project conducted by the Children's Environmental Health Initiative of the Nicholas School of the Environment and Earth Sciences at Duke University.

## ALLERGENS AND ASTHMA TRIGGERS RESULTS

### A. Bulk Dust Samples

The sampling team collected a bulk dust sample from your home. The sample was analyzed for several types of allergens, and the results are reported in micrograms per gram. The table also includes a categorization of the concentration of the different allergens. Please note that there are no regulated levels of allergens in indoor dust. However, the categories listed provide information on what type of health effects may result from the concentrations of allergens found in your home.

| ***Allergen Type*** | ***Results (micrograms per gram)*** | ***Category*** |
|---|---|---|
| Dust Mite p I (*Dermatophagoides pteronyssinus*) | 16.6 | C |
| Dust Mite f I (*Dermatophagoides farinae*) | 4.2 | B |
| Cockroach Allergen | Less than 0.1 | * |

A = low risk factor
B = elevated risk for sensitization
C = elevated risk for symptom exacerbation

* Cockroach allergen levels associated with symptoms in cockroach allergic individuals are not yet well defined. Preliminary evidence indicates, however, that cockroach allergen levels above 2 micrograms per gram may increase the risk of sensitization.

### B. Bioaerosol Samples

The sampling team collected five bioaerosol samples at the residence, including: one from the crawl space; one from the indoor environment before the heating, ventilating, and air-conditioning (HVAC) system fan is turned on; one indoors after the HVAC fan ran for at least 5 minutes; one at a supply air diffuser (or register); and one outdoors. The results include the total number of breathable fungal spores, reported in colony forming units per cubic meter of air (CFU/$m^3$), and the most common types of spores found in each sample taken from your home.

While there are no regulations defining what levels of fungal spores are acceptable in indoor air, we generally expect to see lower concentrations in the indoor sample, when compared to the outdoor sample. We also should find the same types of spores in both samples. If we see significantly higher concentrations of spores indoors, or the types of spores indoors are very different from the types of spores outside, that finding suggests that mold may be growing inside the home.

| | *Crawl Space* | *Indoor (HVAC off)* | *Indoor (HVAC on)* | *Indoor (Diffuser)* | *Outdoor* |
|---|---|---|---|---|---|
| Breathable Spore Count | 1561 CFU/m$^3$ | 1056 CFU/m$^3$ | 1106 CFU/m$^3$ | 267 CFU/m$^3$ | 4326 CFU/m$^3$ |
| Most Common Fungal Spores | 1. Mycelia Sterilia<br>2. Penicillium<br>3. Cladosporium | 1. Penicillium<br>2. Cladosporium<br>3. Mycelia Sterilia | 1. Cladosporium<br>2. Penicillium<br>3. Mycelia Sterilia<br>4. Aspergillus | 1. Mycelia Sterilia<br>2. Penicillium<br>3. Cladosporium | 1. Penicillium<br>2. Cladosporium<br>3. Mycelia Sterilia<br>4. Trichoderma |

These results are difficult to interpret. The indoor concentration of fungal spores was less than the outdoor concentration, and the mix of fungal species was similar. However, the indoor concentrations were higher than what we normally expect to find in a home. There are several possible explanations for these results. First, this type of finding could result from doors and windows being open frequently on or prior to the day of sampling. The types of fungal spores found in and around your home can remain in the indoor air for extended periods and may have caused the higher indoor concentration on the day we sampled. Second, the HVAC system may be pulling in outdoor air. Third, mold may have been growing in your home when we sampled. Because the mix of organisms was similar across all of the samples, it is difficult to distinguish among these different possibilities.

**C. Temperature and Relative Humidity**

Routine monitoring of your home's temperature and relative humidity may help reduce exposures to potential allergen and asthma triggers. Maintaining a relative humidity between 30 and 50 percent can help prevent dust mite infestation and mold growth.

Indoor Temperature: 73.6°F
Indoor Relative Humidity: 64.3%
Outdoor Temperature: 82.0°F
Outdoor Relative Humidity: 73.2%

**D. Moisture Meter Readings**

A moisture meter was used to help determine the relative moisture level at the surface of several walls in your home. In general, the sampling team tested the wall directly behind the kitchen sink, the wall behind a washing machine, the wall containing plumbing for a shower or bath, and the interior surface of a wall facing north. The moisture meter can detect moisture within different building materials of varying thickness. Increased moisture levels within various materials may indicate the presence of water intrusion, which may result in conditions favorable for the growth of mold species.

The moisture meter gauges moisture in relative terms. Therefore, the higher the moisture meter reading, the wetter the building material. The meter reports within three ranges with the following explanations:

**Green** – Air-dry conditions. Decay and/or mold growth unlikely.
**Yellow** – Moisture somewhat in excess of normal.
**Red** – Excess moisture. This condition may result in decay and/or mold growth.

| Location of Moisture Meter Reading | Relative Moisture |
|---|---|
| Kitchen | Green |
| Bath | Green |
| First Floor Bath | Green |
| Laundry | Green |
| Interior of northern wall | Green |

## LIMITED FIRE RISK EVALUATION

CEHI staff conducted an extremely limited fire risk evaluation of your home, which consisted of pushing the test button on smoke detectors. When tested, the smoke detectors in your home beeped.

## SUGGESTIONS FOR FURTHER ACTION

Included in this packet, please find several documents describing indoor environmental controls for asthma triggers, allergens, and fire. These documents, which are distributed by federal agencies, address many questions that may have arisen after reading this report.

Please direct questions regarding indoor air quality to the Occupational and Environmental Epidemiology Division within the North Carolina Department of Health and Human Services at (919) 733-3410. Specific questions regarding fire risks may be addressed to Ms. Jeanne Givens of the North Carolina Department of Health and Human Services Chronic Disease Prevention and Control at (919) 715-6448. Please do not hesitate to contact CEHI at our toll free number with any additional questions or comments, 1-866-264-7891.

# 3.0 EDUCATION AND OUTREACH

The Children's Environmental Health Initiative (CEHI) is a research, outreach, and education program committed to fostering environments where all children can prosper. Evaluating indoor asthma and allergen triggers through this project presented many opportunities to encourage participation in research, as well as offer education and outreach for indoor environmental health more broadly. Individual study participants represented a distinct population to connect with and provide education, through outreach, about the home environment. Outreach and education efforts for participants were achieved through recruitment strategies, sampling visits, organizational networking, and delivery of the participant report. We utilized presentations, publications, and training events to accomplish our outreach and education goals vis-à-vis study participants, community partners, and other stakeholders concerned about indoor environmental exposures.

## 3.1 Participant education and outreach

Recruitment into CEHI's research project and outreach activities often overlapped as CEHI field technicians focused on a three-pronged approach to enrolling participants in the study communities: community based organizational networking, direct mailing, and door-to-door canvassing of target areas. In this way, CEHI staff capitalized on the opportunity to provide outreach and education in addition to enrolling participants into the research project.

Participant education and outreach was an integral component for this project from the first point of contact with potential participants, through the sample collection, to the delivery of the final participant report. Throughout the period of the project, CEHI staff developed and collected materials to distribute to participants in order to communicate risks associated with indoor environmental exposures. Recruitment via direct mailing involved mailing participants a recruitment letter describing the research project and its potential benefits. During call-backs from these mailings, participants were encouraged, and given multiple opportunities, to ask questions regarding the research project or issues regarding indoor environmental exposures in general.

When a sampling visit represented the first point of physical contact with a participant, CEHI technicians addressed participant education in two ways: by on site education and demonstration and by distributing a package of informational brochures to the participants. **Table 3-1** contains a list of commonly used education materials during sampling visits. Prior to sample collection, CEHI technicians made certain that participants understood the elements of the indoor environment that were being sampled, and could ask questions at any point during the visit. Additionally, a toll-free number was included with all CEHI documents distributed to participants. Bilingual CEHI personnel staffed this telephone line to answer questions regarding the project.

The final report distributed to participants was a capstone element for outreach and education to the individual participant. In this report, the research findings were listed quantitatively, along with narrative scientific interpretation accessible to the public. The report went on to suggest a set of recommendations addressing the specific findings and offer additional contacts for further resources. The CEHI toll-free number was included for answering any questions about the final report. A sample final report is included in the Appendix.

In order to maximize participant recruitment and outreach contact, CEHI personnel accessed its established community based organizational networks to approach local service organizations and businesses within the study areas. During these meetings, CEHI personnel talked with organizational leaders about issues related to home environmental exposures, the research project, and resources available to local constituents. CEHI personnel also distributed recruitment flyers to local businesses with CEHI contact information. **Tables 3-2a-c** present a listing of the organizations CEHI personnel contacted through this organizational network approach for each study county.

**Table 3-1. Outreach materials.**

| RISK | TITLE | PUBLISHED BY | WEBSITE |
|---|---|---|---|
| FIRE | | | |
| | Look Up for Fire Safety, Smoke Detectors Save Lives & Spanish version | DHHS | www.hhs.gov |
| | Proteja contra Incendio: 5 pasos para proteger su hogar contra Incendios | DHHS; NCS | www.hhs.gov |
| | English version of previous pamphlet | DHHS; NCS | www.hhs.gov |
| LEAD | | | |
| | It's time to get the lead out | EQI, UNCA, Ashville | www.unca.edu/eqi |
| | Lead poisoning DOS & DON'Ts | NCDENR, CEH Branch | www.enr.state.nc.us |
| | Envenenamiento causado por plomo: Lo que se debe hacer y lo que no | NCDENR, CEH Branch | www.enr.state.nc.us |
| | El Envenenamiento por el plomo y Sus Ninos | US EPA | http://www.epa.gov/oppt/lead/pubs/leadpbed.htm#brochures |
| | Lead Poisoning and Your Children | US EPA | http://www.epa.gov/oppt/lead/pubs/leadpbed.htm#brochures |
| | Lead Poisoning: What Every Family Should Know About Lead Poisoning | Durham Affordable Housing Coalition (DAHC) | www.dahc.org/leadposioning.html |
| | Protect your Familiy from Lead in Your Home EPA-747-K-94-001 | US EPA-CPSC | http://www.hud.gov/offices/lead/outreach/leapame.pdf |
| | Proteja a su familia del plomo en su casa | US EPA-CPSC | http://www.hud.gov/offices/lead/outreach/leadpdfs.pdf |
| | There is Only One Way to know if your child has lead poisoning | California Childhood Lead Poisoning Prevention Branch CDC | http://www.dhs.ca.gov/childlead/html/faq.html#Symptoms |
| | Lead and Your Health NIH-Pub. No. 92-3465 | NIH-NIEHS | www.niehs.nih.gov/oc/factsheets/pdf/lead.pdf |
| | North Carolina's Lead-Based Paint Preventive Maintenance Program | NCDENR, CEH Branch | www.enr.state.nc.us |
| | Programa de Mantenimiento Preventivo de la pintura a base de plomo en NC | NCDENR, CEH Branch | www.enr.state.nc.us |
| | Reducing Lead Hazards When Remodeling Your Home EPA 747-K-97-001 | US EPA | http://www.epa.gov/oppt/lead/pubs/leadpbed.htm#brochures |
| | Caution: Lead Paint Handle With Care | HUD | www.hud.gov/offices/lead/outreach/tradesOKAYTOPRINT.pdf |
| | Lead Paint can Poison: Learn the Facts | HUD | www.hud.gov/offices/lead/outreach/parentsOKTOPRINT.pdf |
| | La Seguridad con la Pintura de Plomo | HUD | http://www.hud.gov/utilities/intercept.cfm?/offices/lead/training/LeadGuide-Sp-6-5.pdf |
| | Lead Paint & Safety | HUD | http://www.hud.gov/offices/lead/training/LBPguide.pdf |

| | | | |
|---|---|---|---|
| | Protegemos a Nuestros Ninos del Envenenamiento del Plomo | Durham Dept. Housing Community Development | www.ci.durham.nc.us/departments/housing |
| | Protect our children from lead poisoning | Durham Dept. Housing Community Development | www.ci.durham.nc.us/departments/housing |
| | The Homeowner's Guide to Lead-Safe Painting & Home Improvement | US EPA | http://www.epa.gov/oppt/lead/pubs/leadpbed.htm#brochures |
| | Fight Lead Poisoning With a Healthy Diet:7 Lead Poisoning Prevention Tips for Families EPA-747-F-01-004 | US EPA | http://www.epa.gov/oppt/lead/pubs/leadpbed.htm#brochures |
| **ASTHMA-ALLERGENS** | | | |
| | Indoor Air Hazards: Every Homeowner Should Know About | US EPA | http://www.montana.edu/wwwcxair/hazards.htm |
| | Facts about Clean Indoor Air in Child Care | Amercian Lung Association | www.lungusa.org |
| | Don't Let Asthma Knock the Wind Out of Your Child | State of NY, Dept. of Health | www.health.state.ny.us/nysdoh/asthma/brochures/4819.htm |
| | No permita que el Asma corte las alas de su hijo | State of NY, Dept. of Health | www.health.state.ny.us/nysdoh/asthma/brochures/4831.htm |
| | ZAP Asthma | ZAP Asthma | http://www.sph.emory.edu/zapasthma/healthed.htm |
| | Cleaning to Control Allergies & Asthma | ZAP Asthma | www.cleaning101.com/health/allergies/sdayouth5-5.pdf |
| | A brief guide to Mold, Moisture and Your Home | US EPA | http://www.epa.gov/mold/moldguide.html |
| | Asthma Triggers and Management | American Academy of Allergy, Asthma & Immunology | www.aaaai.org/patients/publicedmat/tips/asthmatriggersandmgmt.stm |
| | Indoor Alllergens | American Academy of Allergy, Asthma & Immunology | www.aaaai.org/patients/publicedmat/tips/indoorallergens.stm |
| | Prevention of Allergies and Asthma and Asthma in Children | American Academy of Allergy, Asthma & Immunology | www.aaaai.org/patients/publicedmat/tips/preventioninchildren.stm |
| | Spanish version of AAAAI pamphlets | American Academy of Allergy, Asthma & Immunology | http://www.aaaai.org/espanol/ |
| | I feel like a fish with no water | US EPA | http://yosemite.epa.gov/ochp/ochpweb.nsf/content/otherpubs2.htm |
| | Me siento como un pez sin agua | US EPA | http://yosemite.epa.gov/ochp/ochpweb.nsf/content/otherpubs2.htm |
| | Mold Control: Tipos for Identifying & Eliminating household mold | Canada / NACTF / LCDC / | www.healthhouse.org/tipsheets/TS_MoldControl.pdf |
| | Mold, Moisture & Your Home | US EPA | www.epa.gov/iaq/molds/moldguide.html |
| | Clear your Home of Asthma Triggers: Your children will breathe easier Doc. 402F99005 | US EPA | www.epa.gov/asthma/pdfs/asthma_eng.trifold.pdf |
| | Asma: Puede respirar mas facilmente | US EPA | http://yosemite.epa.gov/ochp/ochpweb.nsf/content/otherpubs2.htm |

**Table 3-2a. Durham County points of contact for participant education and outreach.**

| Service Organizations and Local Businesses | Outreach and Educational Access |
|---|---|
| Durham CAN organizations | Organization working with low income, minority clientele |
| Immaculate Conception Catholic Church | Religious institution serving large numbers of minorities |
| Walltown Neighborhood Ministries | Religious institution serving large numbers of minorities |
| Blacknall Presbyterian Church | Religious institution serving large numbers of minorities |
| Asbury Temple Methodist Church | Religious institution serving large numbers of minorities |
| Calvary United Methodist Church | Religious institution serving large numbers of minorities |
| Greater St Paul Baptist Church | Religious institution serving large numbers of minorities |

**Table 3-2b. New Hanover County points of contact for participant education and outreach.**

| Service Organizations and Businesses | Outreach and Educational Access |
|---|---|
| Amigos International | Organization working with Hispanic community |
| Brigrade Boys and Girls Club | Organization working with low income, minority clientele |
| Leading Into New Communities (L.I.N.C.) | Organization working with low income, minority clientele |
| Wal-Mart | Large scale employer of minorities |
| Folks Coffee Shop | Store located in or serving minority neighborhood |

**Table 3-2c. Wilson County points of contact for participant education and outreach.**

| Service Organizations and Businesses | Outreach and Educational Access |
|---|---|
| Walmart | Large-scale employer of minorities |
| Lowes | Large-scale employer of minorities |
| Staples | Large-scale employer of minorities |
| Eckerds | Store located in or serving minority neighborhood |
| Piggly Wiggly | Store located in or serving minority neighborhood |
| Thomas Drug Store | Store located in or serving minority neighborhood |
| El Tapatio Restaurant | Store located in or serving minority neighborhood |
| Wilson Police Department, South District Station | Access to community outreach board |
| Bridgestone/Firestone Plant | Large-scale employer of minorities |
| Wison Technical Community College | Access to students, and community outreach board |
| Wilson Public Library | Access to community outreach board |
| Wilson Hospital | Access to community outreach board |
| United Way of Wilson | Organization working with low-income, minority clientele |
| Wilson Mental Health Association | Organization working with low-income, minority clientele |
| The Arc of Wilson | Organization working with low-income, minority clientele |
| Volunteer Action Center | Organization working with low-income, minority clientele |
| Wilson County Human Relations Office | Government office connected to Hispanic community |

## 3.2 Local Community Education and Outreach

CEHI conducted outreach and education activities through presentations, community events, publications, organizational networking, and skills training. Community education and outreach activities leveraged existing and newly developed partnerships with community-based organizations, religious institutions, government agencies, and other research and outreach organizations. In this way, CEHI outreach efforts offered resources for indoor environmental sampling, educational information and materials, and partnership opportunities to organizations supporting indoor environmental interventions.

Publications and presentations related to indoor environment exposures presented opportunities to connect with other research organizations, government agencies, and community groups. Throughout the period of this project, CEHI personnel gave seven presentations to conference audiences, including research, academic, and community stakeholders. For a complete listing of indoor environmental exposure related presentations, see **Table 3-3**. In addition to conference presentations, manuscripts prepared for publication in scholarly journals include ones on seasonal variation in home fungal levels, home bioaerosol levels, home bulk dust levels, the co-occurrence of bioaerosol and bulk dust problems, crawlspace fungal transmission, and the use of non-invasive crawlspace sampling techniques (see section 3.3 for submission details). Published materials also include two official reports from HUD subgrantee Advanced Energy (AE) detailing crawlspace characterization findings from this project. Prior to approval, Advanced Energy's initial draft was reviewed by Drs. Hale, Miranda, and Thomann, as well as Mr. Stiegel. Comments were incorporated in the final draft, which was again reviewed by ale, Miranda, Thomann, and Stiegel.

**Table 3-3. Presentations.**

| Title | Year | Conference/Venue |
|---|---|---|
| GIS Models of Childhood Exposures to Allergens and Asthma Triggers in the Home Environment. | Oct. 2002 | CDC National Asthma Conference |
| GIS-Based Strategies for Addressing Respiratory Disease and Air Quality Concerns in Children. | Feb. 2003 | National Institutes of Environmental Health Sciences (NIEHS) |
| GIS-Based Strategies for Addressing Children's Environmental Health:GIS Mapping of Housing Data for Targeting and Advocacy | April 2003 | Community Environmental Health Resource Center (CEHRC) |
| Shared Air: Examining the Contribution of Mold from Home Crawlspaces to Home Interiors. | Sept. 2003 | International Conference on Bioaerosols, Fungi, Bacteria, Mycotoxins and Human Health |
| Something to Sneeze at: Trends in Air- and Dust-Borne Allergens in Central and Eastern North Carolina | June 2004 | Healthy Homes Conference |
| Children and Exposure to Indoor Pollutants | Feb. 2005 | UNC School of Public Health, Minority Health Conference |
| Co-exposure to Bulk Dust and Bioaerosol Allergens and Asthma Triggers in the Home Environment | Dec. 2005 | American Public Health Association |

CEHI personnel regularly gave lay audience presentations to government agencies that are stakeholders in these issues, including: the Durham City Council, the Guilford County Department of Health, the Forsyth County Department of Health, the North Carolina Lead Ad Hoc Advisory Council, the North Carolina State Asthma Alliance, and officials from Buncombe and Henderson Counties. Many presentations were held for community-based organizations throughout the project, including organizations such as those listed in **Table 3-4**. These presentations were most often held at organizational meetings or community events. Examples of community fairs attended by CEHI personnel include: El Fiesta De Salud in Durham, El Foro Latino in Greensboro, La Fiesta Del Pueblo in Raleigh, and the Lead Poisoning Prevention Fair at Eastway Elementary School in Durham. Organizations included in **Table 3-4** are central to the regular and active partnerships that comprise CEHI's organizational network.

**Table 3-4. Collaborating community agencies.**

| | |
|---|---|
| Asthma Alliance of North Carolina | The Asthma Alliance of North Carolina is a statewide partnership of local and state government agencies, academic institutions, local asthma coalitions, non-profits, and private industry working collaboratively to address asthma. The mission of the Asthma Alliance of NC is to reduce asthma morbidity and mortality for all people in North Carolina through a comprehensive public health approach. |
| Ad Hoc Lead Advisory Committee | The NC Children's Environmental Health Branch Ad hoc Lead Advisory Committee is a group that meets on a quarterly basis to share ideas, concerns, and strategies for heightened awareness and prevention of childhood lead poisoning throughout the state of North Carolina. The Ad hoc Committee is comprised of representatives from state and local health and housing-oriented agencies, community-based organizations, and institutions of higher education. |
| Community Partners Against Lead (CPAL) | Community Partners Against Lead (CPAL) is a lead outreach and intervention organization combining the interests, resources, and expertise of stakeholders in the issue of childhood lead poisoning and substandard housing. The mission of CPAL is to eliminate childhood lead poisoning in Durham County by 2010 using housing, education, and health initiatives using housing, education, and health initiatives. |
| Durham Congregations, Associations, and Neighborhoods (CAN) | Durham CAN is based on the broad organization model of the national Industrial Areas Foundation (IAF). IAF leaders build relationships by holding hundreds of individual meetings where two people sit down to talk, share stories, agitate, challenge, share common visions, and build leadership networks. |
| Durham Affordable Housing Coalition (DAHC) | The DAHC mission is to promote safe, fair and affordable housing in Durham, North Carolina. |
| Durham Parents Against Lead (DPAL) | DPAL is a group of parents of lead-poisoned children who are active in outreach and education. The mission of DPAL is to provide outreach to all parents and caregivers in Durham and to collaborate with local community groups, agencies, and organizations to eliminate lead poisoning through education, parent support, advocacy, resource referral, and legislative action. |
| East Coast Migrant HeadStart Program (ECMHSP) | ECMHSP establishes, provides, and promotes continuity of Head Start services to migrant children and their families along the East Coast of the United States. |
| El Centro Hispano | El Centro Hispano is a community-based organization with a mission to improve the quality of life and well being of working class Latino immigrants in Durham County and surrounding areas. |
| Hispanic Outreach Taskforce | The Hispanic Outreach Taskforce is a component organization of the Ad Hoc Lead Advisory Committee with the specific intention with connecting and educating North Carolina's growing Hispanic population on issues of healthy home environments. |
| North Carolina Rural Community Assistance Project (NCRCAP) | NCRCAP is a statewide nonprofit organization with the mission to provide assistance to low-income, rural communities on public health and environmental quality issues pertaining to water, wastewater, solid waste, and affordable housing needs. |

**Table 3-4 (continued). Collaborating community agencies.**

| | |
|---|---|
| Orange County Hispanic Task Force | The Orange County Hispanic Task Force is an organization that brings together leaders of the Hispanic community to collaborate, empower, and support Hispanic residents of Orange County. |
| Partnership Effort for the Advancement of Children's Health (PEACH) | The goal of PEACH is to address environmental insults in children of color who live in deteriorated housing, older housing, and low income communities. PEACH was founded as a community partnership between North Carolina Central University (NCCU) and the North East Central Durham (NECD) community based agency. |

Partnering with community organizations provided opportunities to expand home environmental sampling and connect with large numbers of individuals through organizational networking. CEHI supported the work of Community Partners Against Lead (CPAL) by providing GIS mapping resources for planning and targeting neighborhood level outreach events. Using these maps, CPAL targets the most at-risk neighborhoods in Durham for a series of door-to-door neighborhood events. Free services offered include blood testing for children under 6, in-home screening for lead, education for home-owners in lead safe practices, and recruitment of eligible participants into city rehabilitation and abatement programs. In 2004, CPAL successfully organized 8 door-to-door outreach events in target neighborhoods. Of the 635 homes that CPAL contacted during these community outreach events, 63% requested home and/or blood lead testing. During the community events, CPAL also identified 488 vacant houses; this data was incorporated into the City’s vacant housing survey. Of the 302 homes screened for lead, 64% had lead present, and 35% had lead hazards. All homes with lead hazards and children under the age of 6 were directed to the City’s lead remediation program. In addition, CPAL works with residents to clean homes and teach residents methods for reducing lead risks in the home. CPAL is also working with landlords, using both incentives (like North Carolina’s Preventive Maintenance Program) and pressure (housing code enforcements and community self-advocacy) to improve housing quality in these high risk neighborhoods.

CEHI also partnered with the North Carolina Rural Communities Assistance Project, Inc. (NCRCAP) to expand indoor environmental sampling opportunities to Latino residents of Chatham County. CEHI and NCRCAP combined resources to offer bioaerosol and bulk dust sampling to Latino families recruited by NCRCAP. The results from sampling were formulated in a Spanish language report given to participants detailing the findings for indoor mold and dustborne allergen triggers. Educational Spanish language materials about other environmental health topics such as lead poisoning and pesticide exposure were also distributed to participants.

CEHI’s special expertise in spatial analysis and GIS tools provided the means to conduct training events for community partners with three main themes: using GIS as an outreach tool, capacity building through GIS development, and communicating data fundamentals. CEHI’s profile of training resources included workshops for indoor air quality, GIS training for lead poisoning prevention, spatial database construction, and management of environmental health data. The range of audiences for these trainings included researchers, public health workers, migrant family service providers, and community organizers. A recent example illustrating CEHI’s training themes was a two-day workshop held in October 2005 for environmental health workers from local health departments titled: “Using GIS Approaches to Direct Children’s Environmental Health Programs”. During this workshop, attendees were trained to use GIS software and applications as a multi-faceted tool for designing preventive intervention programs in environmental health.

Overall, CEHI outreach efforts exceeded benchmark expectations in both outreach events and meetings, and skills training events. CEHI participated in seventy-five total meetings and events during the period of the project, exceeding the goal of fifty events by fifty percent (**Figure 3-1**). However, this number does not capture the entire scope of inter-organizational contacts that are common in CEHI's partnerships. Regardless of whether a meeting is official or scheduled, CEHI personnel interact regularly with community partners to answer questions, provide resources, or assist with using GIS. Where CEHI's goal was to have a total of ten training events, there were eighteen events held where CEHI was able to promote its training themes of using GIS as a tool, GIS capacity building, and improving data management (**Figure 3-2**).

**Figure 3-1. Outreach benchmarks**

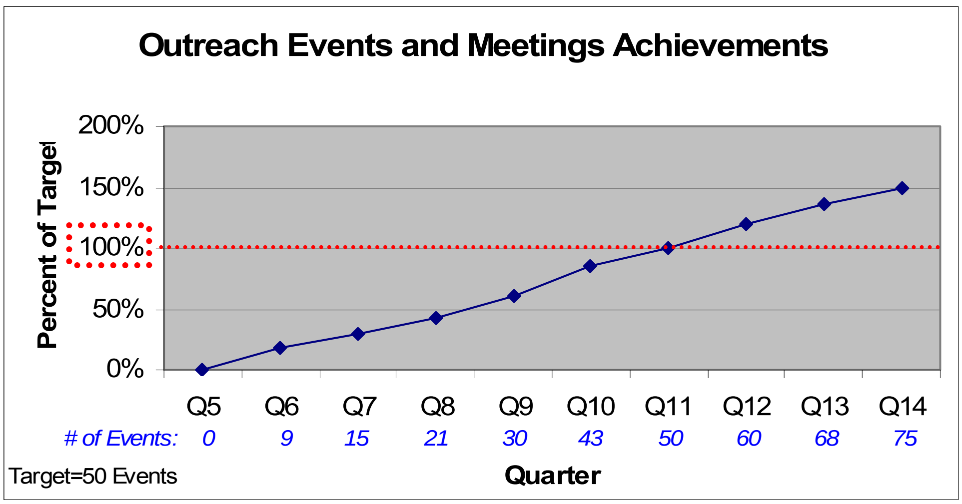
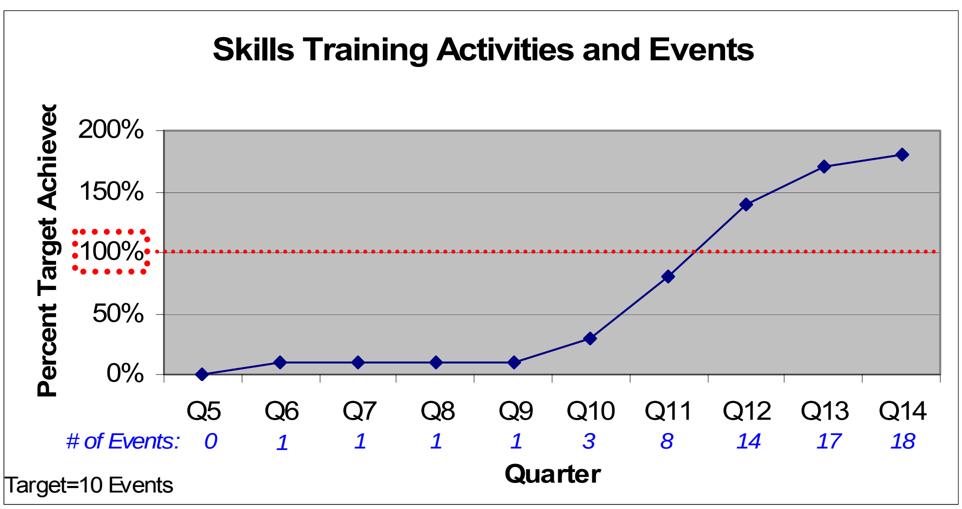



**Figure 3-2. Skills training benchmarks**



Outreach and education are not static processes. They are dynamic, growing as partners develop, align organizational resources, and articulate interests. With the improvement of in-house expertise comes the expanded opportunity to provide more resources for training partners and stakeholders. The outreach and education strategies of CEHI reflect this organic approach toward communicating and educating on the individual and community levels. Operating dual mechanisms for participant and community outreach enhanced the ability of CEHI to connect with its target populations and maximize educational impact.

## 3.3 Appendix I: Manuscript Submission

**Table A3-1: Status of grant-related manuscripts**

| Paper topic | Status |
|---|---|
| 1) Seasonal variation in fungal communities | Submitted—in review |
| 2) Bioaerosols in the home environment | Undergoing internal review |
| 3) Dustborne allergens in the home environment | Undergoing internal review |
| 4) Co-occurrence of bioaerosol and dustborne allergens | Undergoing internal review |
| 5) Influence of crawlspace construction on indoor bioaerosol levels | Undergoing internal review |
| 6) Non-invasive crawlspace sampling | Undergoing internal review |

## 3.4 Appendix II: Listing of Information Dissemination

**1. GIS Models of Childhood Exposures to Allergens and Asthma Triggers in the Home Environment.**

- Author(s): M.L. Miranda, W.R. Thomann, M. Abrams, D.C. Dolinoy, M.A.Overstreet
- Title: GIS Models of Childhood Exposures to Allergens and Asthma Triggers in the Home Environment
- Date: October 23, 2002
- Venue: CDC National Asthma Conference, Atlanta, GA
- Audience:
- Abstract:
  Purpose: Use GIS to assess allergen and asthma trigger risks in the home environment.
  Methods: The project characterizes the housing stock in four NC counties to allow comparisons across social, economic, and ecological zones. To calibrate the model, we are collecting environmental samples in 500 homes, including a composite indoor bulk dust sample, as well as bioaerosol samples collected from the crawlspace and inside the livable part of the home. The resulting model characterizes risk of exposure to allergens and asthma triggers across space.
  Results: Preliminary analysis indicates that mean concentrations of dust mite and cockroach allergens are all well above levels considered to cause sensitization and symptom exacerbation, although there is high variability. The most common types of spores found in the indoor bioaerosol samples were *Cladosporium, Penicillium, Mycelia sterilia, Basidiomycetes,* and *Aspergillus.* Multivariate analysis is used to compare allergen levels with physical characteristics, housing stock variables, and demographics.

Substantial differences in bulk dust and mold allergens exist across the explanatory variables used in the multivariate analysis, as well as across the sample counties and seasons.

Conclusions: GIS models can provide a better understanding of allergens and asthma triggers in the home environment, eventually enhancing health care management.

**2. GIS-Based Strategies for Addressing Respiratory Disease and Air Quality Concerns in Children.**

- Author(s): M.L. Miranda
- Title: GIS-Bases Strategies for Addressing Respiratory Disease and Air Quality Concerns in Children
- Date: February 24, 2003
- Venue: National Institute of Environmental Health Sciences, Research Triangle Park, NC
- Audience: NIEHS administrators, researchers, and staff
- Abstract:
  Topics covered during this presentation included:
  - Factors that influences on Respiratory Health
  - Environmental and health factors that can be geographically referenced
  - Visualizing children's health disparities as a complex interaction of social stressors, environmental exposures, and genetic exposures.
  - Articulating research and policy questions relevant to children's environmental health

**3. GIS-Based Strategies for Addressing Children's Environmental Health: GIS Mapping of Housing Data for Targeting and Advocacy.**

- Author(s): M.A. Overstreet, M. Abrams
- Title: GIS-Based Strategies for Addressing Children's Environmental Health: GIS Mapping of Housing Data for Targeting and Advocacy
- Date: April 5, 2003
- Venue: Community Environmental Health Resource Center Grantee Meeting, Greensboro, NC
- Audience: North Carolina based housing advocates, environmental health workers, and community members
- Abstract:
  Topics covered in this presentation include:
  - The use of GIS as a tool to guide community based participatory research
  - Identifying environmental exposures in the home environment
  - Identifying areas of GIS application that are most useful to community organizations

**4. Shared Air: Examining the Contribution of Mold from Home Crawl Spaces to Home Interiors.**

- Author(s): W.R. Thomann, M.L. Miranda, M. Stiegel, M.A. Overstreet
- Title: Shared Air: Examining the Contribution of Mold from Home Crawl Spaces to Home Interiors.
- Date: September 9, 2003
- Venue: International Conference on Bioaerosols, Fungi, Bacteria, Mycotoxins, and Human Health, Saratoga Springs, NY

- Audience: Scientists specializing in indoor air quality, respiratory health, bioaerosols, fungi, bacteria, and mycotoxins.
- Abstract:
  Mounting evidence suggests that exposure to mold in damp buildings is an important risk factor for childhood respiratory illness. One potential source of a "damp" home is crawl space construction. In recent studies we assessed mold contamination levels within crawl spaces and characterized whether air leakage from the heating, ventilation and air conditioning (HVAC) system, and associated ductwork, transports viable mold spores from the crawl space into the living spaces within the home. The sampling protocol involves the use of an Andersen two-stage impaction sampler to collect viable mold spores from the crawl space, the interior of the home, "supply" air coming directly from the HVAC system, and the outdoors. Results from 70 homes confirmed that crawl spaces are potentially important reservoirs of mold species that appeared to be transported into the occupiable areas of the home environment in 37% of the houses investigated. The HVAC system was identified as a vehicle for transmission of this contamination from the crawl space into the living spaces. Potential causes of the mold growth and spore distribution appear to be inadequate insulation of cold surfaces in the crawl space, leading to extensive condensation, and air leakage in the HVAC system and ductwork.

**5. Something to Sneeze at: Trends in Air- and Dust-Borne Allergens in Central and Eastern North Carolina.**

- Author(s): M.L. Miranda, W.R. Thomann, B. Hale, M.A. Overstreet, C. Pungiluppi-Tono, M.Stiegel
- Title: Something to Sneeze at: Trends in Air- and Dust-Borne Allergens in Central and Eastern North Carolina.
- Date: June 21, 2004
- Venue: Healthy Homes Conference, Orlando, FL
- Audience: Housing and health advocates, researchers, and community organizers
- Abstract:
  The Children's Environmental Health Initiative (CEHI) at Duke University is developing a spatially-based model to characterize exposures to allergens and asthma triggers. To support model development, CEHI has collected composite indoor bulk dust and bioaerosol samples in 500 homes. Mean concentrations of bulk dust allergens are well above levels considered to cause sensitization and symptom exacerbation with high variability across homes. A significant number of homes demonstrate high levels of mold, especially in North Carolina's coastal plain.

**6. Co-exposure to Bulk Dust and Bioaerosol Allergens and Asthma Triggers in the Home Environment.**

- Author(s): W.R. Thomann, M.L. Miranda, B.Hale, M. Stiegel, J.A. Davis, M.A. Overstreet
- Title: Co-exposure to Bulk Dust and Bioaerosol Allergens and Asthma Triggers in the Home Environment.
- Date: December
- Venue: 133rd Annual conference of the American Public Health Association, Philadelphia, PA
- Audience: Public health workers, environmental health researchers, community organizers
- Abstract:

Children today spend an estimated 90% of their time indoors; as such, the home environment plays a crucial role in children's environmental health. Specific subpopulations, such as minorities, poor families, and families living in urban environments, may face elevated exposures to allergens and asthma triggers. The Children's Environmental Health Initiative (CEHI) at Duke University is especially interested in how various home health risks shape children's health outcomes. CEHI has collected environmental samples in over 1000 homes in Central and Eastern North Carolina, including a composite indoor bulk dust sample and bioaerosol samples taken in both the crawlspace and inside the inhabited part of the home. Initial findings indicate a high proportion of homes with elevated dust mite and roach allergen, as well as indoor mold, levels. The substantial variation in allergen and asthma trigger levels is characterized by systematic geographic variation. As one of the few field studies to collect both bulk dust and bioaerosol environmental samples, our analysis provides unique insights into joint exposures to two critical classes of respiratory irritants in the home environment.

**Table A3-2: Date and venues of Grant-related presentations.**

| Title | Authors | Year | Conference/Venue |
|---|---|---|---|
| GIS Models of Childhood Exposures to Allergens and Asthma Triggers in the Home Environment. | M.L. Miranda, W.R. Thomann, M. Abrams, D.C. Dolinoy, M.A.Overstreet | October, 2002 | CDC National Asthma Conference |
| GIS-Based Strategies for Addressing Respiratory Disease and Air Quality Concerns in Children. | M.L. Miranda | February, 2003 | National Institutes of Environmental Health Sciences (NIEHS) |
| GIS-Based Strategies for Addressing Children's Environmental Health: GIS Mapping of Housing Data for Targeting and Advocacy | M.A. Overstreet, M. Abrams | April, 2003 | Community Environmental Health Resource Center (CEHRC) |
| Shared Air: Examining the Contribution of Mold from Home Crawl Spaces to Home Interiors. | W.R. Thomann, M.L. Miranda, M. Stiegel, M.A. Overstreet | September, 2003 | International Conference on Bioaerosols, Fungi, Bacteria, Mycotoxins and Human Health |
| Something to Sneeze at: Trends in Air- and Dust-Borne Allergens in Central and Eastern North Carolina | M.L. Miranda, W.R. Thomann, B. Hale, M.A. Overstreet, C. Pungiluppi-Tono, M.Stiegel | June 2004 | Healthy Homes Conference |
| Co-exposure to Bulk Dust and Bioaerosol Allergens and Asthma Triggers in the Home Environment | W.R. Thomann, M.L. Miranda, B.Hale, M. Stiegel, J.A. Davis, M.A. Overstreet | December, 2005 | American Public Health Association |

3.5 Lead hazard and poisoning outreach work with Community Partners against Lead

**Figure A3-1: Lead risks in Durham NC and Locations of Homes Sampled in collaboration with CPAL.**

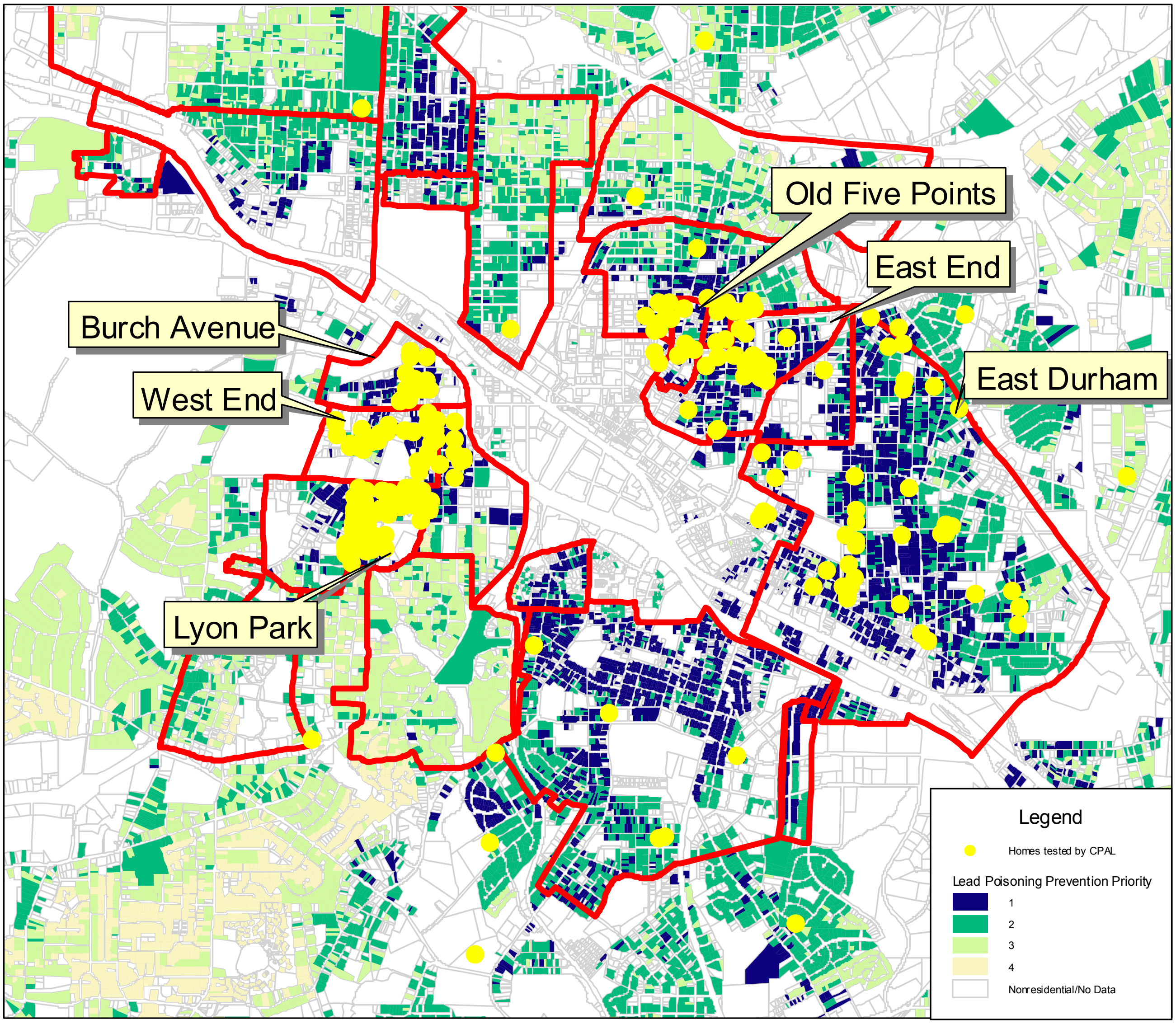


**Table A3-4: Results of home sampling outreach in collaboration with Community Partners Against Lead (CPAL).**

| Event Date | Target Neighborhood | # Houses Tested | % Houses with Lead Found | % Houses with Lead Found beyond Hazard Level | % Houses with Lead Found, with Children under 6 |
|---|---|---|---|---|---|
| 1/24/2004 | Lyon Park | 14 | 71.4 | 57.1 | 28.6 |
| 3/27/2004 | Lyon Park | 31 | 54.8 | 29.0 | 45.2 |
| 4/24/2004 | Lyon Park | 30 | 63.3 | 33.3 | 56.7 |
| 5/22/2004 | West End | 30 | 56.7 | 40.0 | 46.7 |
| 6/19/2004 | West End | 27 | 77.8 | 37.0 | 70.4 |
| 8/28/2004 | East End, Old Five Points | 43 | 72.1 | 39.5 | 69.8 |
| Sept. 2004* | East End, Old Five Points | 68 | 55.9 | 25.0 | 50.0 |
| 10/16/2004 | East Durham | 39 | 59.0 | 41.0 | 53.8 |
| 11/6/2004 | East Durham | 32 | 81.3 | 40.6 | 50.0 |
| Total | | 314 | 64.3 | 35.7 | 53.8 |

# 4.0 RESEARCH FINDINGS

## 4.1 General Sampling Methodology

This section describes our general sampling methodology and is relevant to all the work conducted by Duke University. Within each of the following sections, we also provide additional methodology relevant to specific research assessments. As described in section 3.2, we recruited interested participants through a combination of letter-based and community based recruitment approaches. Interested participants called our toll-free number. CEHI screened them to make sure they met eligibility criteria and briefly explained the project, the time and effort involved in a home sampling session, the benefits it would bring to the participant, and any potential problems incurred by the participant (e.g., turning off air conditioning four hours prior to sampling visit). If the participant agreed to participate, we obtained their contact information, scheduled a visit, completed the initial part of our survey, and fielded any potential questions the participant might have. Upon arrival at the scheduled appointment time, CEHI field staff obtained written, informed consent according to a university-approved Institutional Review Board protocol. The home sampling appointment lasted approximately 30-45 minutes and included completion of the survey, and conducted the in-home sampling.

Allergen and asthma trigger sampling consisted of bioaerosol sampling for viable airborne mold particles and spores. Field technicians also collected vacuum bulk dust samples for allergen and asthma triggers. For all study houses, technicians also collected interior moisture, temperature, and relative humidity readings including the presence and status of smoke detectors. They also administered a survey to the participants regarding general housing characteristics.

### *4.1.1 Bioaerosol Sampling Methodology*

Using an OEM Anderson two-stage cascade impactor collecting particles on two malt extract agar 100-mm Petri dishes [1], CEHI staff sampled indoors and outdoors, near the exterior door identified as the most commonly used. **Table 4-1** shows the locations in the home where we sampled. Depending on the stage of the research project (original award versus crawlspace amendment) and housing characteristics, we sampled in two locations (O, I2), five locations (I1, O, CS2, I3, Diff2), or eight locations (I1, O, CS1, I2, Diff1, CS2, I3, Diff2). For all homes, we collected the samples in the order listed in **Table 4-1**.

The Anderson was calibrated at 28.3 liters of air per minute. We ran the Anderson for 3.5 minutes to obtain each sample (with the exception of CS1 and CS2, where we ran the Anderson for one minute). Between each sample, we cleaned the Anderson using pads saturated with 70% isopropyl alcohol. Our analysis focused on the second stage of the impactor, which collects particles 0.8 to 8 μm (i.e. the respirable fraction). After sample collection, we incubated the Petri dishes in the laboratory at room temperature (25 ºC) for 96-120 hours. For each sample collected, we counted and speciated the colony forming units (CFU/$m^3$) in the second stage dishes. To avoid underestimating fungal counts, we employed the positive-hole corrections found in Willeke and Macher [2]. Fungal identification was accomplished by macroscopic examination of colony morphology and microscopic examination of fungal elements. We used Larone [3] to classify all of the fungi into one of the following groups: *Aspergillus* spp., *Cladosporium* spp., *Penicillium* spp., *Mycelia sterilia*, and Other. The first three groups are common allergens that are often found in homes [4]. *Mycelia sterilia* are a group of sterile fungi that have also been implicated in respiratory problems in children [5,6]. The “Other” category allowed us to express the level and fraction of fungal spores not accounted for by these four most common groups.

**Table 4-1. Bioaerosol sample codes.**

| Sample Order | Sample | Code | Location |
|---|---|---|---|
| 1 | Indoor One | I1 | Near the return vent for the HVAC system; HVAC off for 4+ hours. |
| 2 | Crawlspace One | CS1 | Non-invasive crawlspace sample, using sampler-on-a-stick; HVAC off for 4+ hours (**Figure 4-1**). |
| 3 | Outdoor | O | Outside, near most commonly used door, as identified by resident. |
| 4 | Indoor Two | I2 | Near the return vent for the HVAC system; HVAC on for >5 minutes. |
| 5 | Diffuser One | Diff1 | From the first diffuser that comes off the HVAC system; HVAC on for >5 minutes (**Figure 4-2**). |
| 6 | Crawlspace Two | CS2 | Invasive crawlspace sample, near the first drop off the HVAC system. |
| 7 | Indoor Three | I3 | Near the return vent for the HVAC system; >5 minutes after CS2 sample. |
| 8 | Diffuser Two | Diff2 | From the first diffuser that comes off the HVAC system; >5 minutes after CS2 sample. |

**Figure 4-1. Non-invasive crawlspace sampling (CS1)**

**Figure 4-2. Diffuser sampling (Diff1 and Diff2)**

### *4.1.2 Bulk Dust Sampling Methodology*

Using an Eureka "9amp, The Boss Mighty Might" vacuum (**Figure 4-3**), we sampled the floor and mattresses in the master and children's bedrooms, the indoor play area, the living room, the kitchen, and on upholstered furniture. We used one dust sample collection bag per home for an aggregate sample, which had to contain no less than 500 mg of dust. Bulk dust samples collected were sent to Air Quality Sciences (AQS) in Atlanta, Georgia for analysis. For each sample collected (one per home), the Nicholas School received a report containing concentrations of: dust mite *Dermatophagoides pteronyssinus* (Der p1) allergen in micrograms per gram, dust mite *D. farinae* (Der f1) allergen in micrograms per gram, and cockroach *Blattella germanica* (Bla g1) allergen in micrograms per gram. AQS also analyzed the samples for composite fungal allergens in colony forming units per gram.

Figure 4-3. The **Boss Mighty Might" vacuum**

## 4.2 Seasonal Variation in Indoor Bioaerosols

This part of the project takes advantage of a subsample of 62 homes, in which we sampled during both the cool months (December through March) and the warm months (April through October) in North Carolina. It examined the seasonal variation in indoor environments. A study by Shelton et al. [7] found that overall fungal counts were much higher in the Southeast than the Northeast. Most studies of ambient and indoor fungi levels have been undertaken in cooler temperate climates that experience extended periods of sub-freezing temperatures and significant snow cover, such as the Northeastern United States and Canada. Since fungal levels vary seasonally, and seasonal trends have been a confounding factor in many existing studies [8], there is a strong need for studies on the seasonality of fungal levels relevant to the Southeastern United States. Our study areas in North Carolina provided an excellent opportunity for filling this gap.

### *4.2.1 Methods and Analysis*

To investigate seasonal variation in fungal communities in our study area, we collected warm and cool month bioaerosol samples. Following the methodology described in **Section 4.1.1**, we obtained data for total fungal count and for each mold species grouping. In contrast to the described methodology, in this analysis we did not identify *Mycelia sterilia* (except where discussed below) and these fungi are part of the "Other" grouping. From this, we calculated the proportion of each grouping in the overall fungal community. For each season, we calculated the frequency of detection for each grouping. We also calculated mean and median total fungal count, as well as the mean and median fungal count for each grouping by season. Lastly, we calculated mean temperature and relative humidity for each season.

To examine differences across sampling seasons, we analyzed the total fungal count and fungal counts by groups for the indoor and outdoor communities, respectively. Due to the non-normal distribution of the data, we used a Wilcoxon matched pairs signed rank test to test for significant differences across groups. We also analyzed the data on relative humidity and temperature collected at the same time as the fungal samples for seasonal differences. As these data possessed normal distributions, we used a two-sample t-test for paired data.

We also analyzed possible correlations between indoor and outdoor communities across sampling seasons using a Spearman rank correlation test. Since data containing multiple paired zeros can bias correlation coefficients and may give faulty estimates of statistical significance, we excluded samples with paired zeros [9]. For all of the above analyses, we used STATA 9.0. For all statistical tests, we employed an *alpha* of 0.05.

### *4.2.2 Results*

*Environmental conditions.* The outdoor and indoor environments showed significant differences across sampling seasons (**Table 4-2**). The outdoor relative humidity during the cool months averaged 45.0 percent, significantly lower than the value for the warm months, 59.0 percent ($t=3.51$, $p=0.001$). During the cool months, the average outdoor temperature (12.0 ºC) was significantly lower than the warm months (24.1 ºC; $t=8.0$; $p< 0.001$). The indoor relative humidity also showed significant differences throughout the year, averaging 40.0 percent during the cool months and 52.7 percent during the warm months ($t=6.14$, $p < 0.001$). During the cool months, indoor temperature averaged 19.9 ºC, significantly lower than the warm months value of 23.8 ºC ($t=6.32$, $p< 0.001$).

**Table 4-2. Mean relative humidity and temperature across sampling locations and seasons (± standard error). All values differ significantly across seasons, p<0.001.**

| Location | Season | Relative Humidity (%) | Temperature (ºC) |
|---|---|---:|---:|
| Indoor | Cool months | 40.0 ± 1.6 | 19.9 ± 0.3 |
| | Warm months | 52.7 ± 1.5 | 23.8 ± 0.5 |
| Outdoor | Cool months | 45.0 ± 3.1 | 12.0 ± 1.2 |
| | Warm months | 59.0 ± 3.1 | 24.1 ± 0.9 |

*Fungal Presence.* Our investigations found airborne fungi in all of the sampled homes in both time periods (**Figure 4-4a**). The outdoor samples almost always contained *Cladosporium* (98 percent) in both seasons. This was generally the case for the “other” grouping as well (87 percent), though 13 percent of the sample locations only had fungal species in this group during the cool months. *Penicillium* was also frequently present during both seasons (79 %), although some homes had *Penicillium* only in the cool months (6 %) or only in the warm months (11 %). *Aspergillus* showed a very different trend; it was present in less than 20 percent of the homes and was primarily present only in the warm months (15 %). Overall, the indoor samples followed similar trends to the outdoor samples (**Figure 4-4b**), with just slightly more homes having the various fungal groups present only during the warm months.

**Figure 4-4a. Detection frequency in outdoor samples by season**

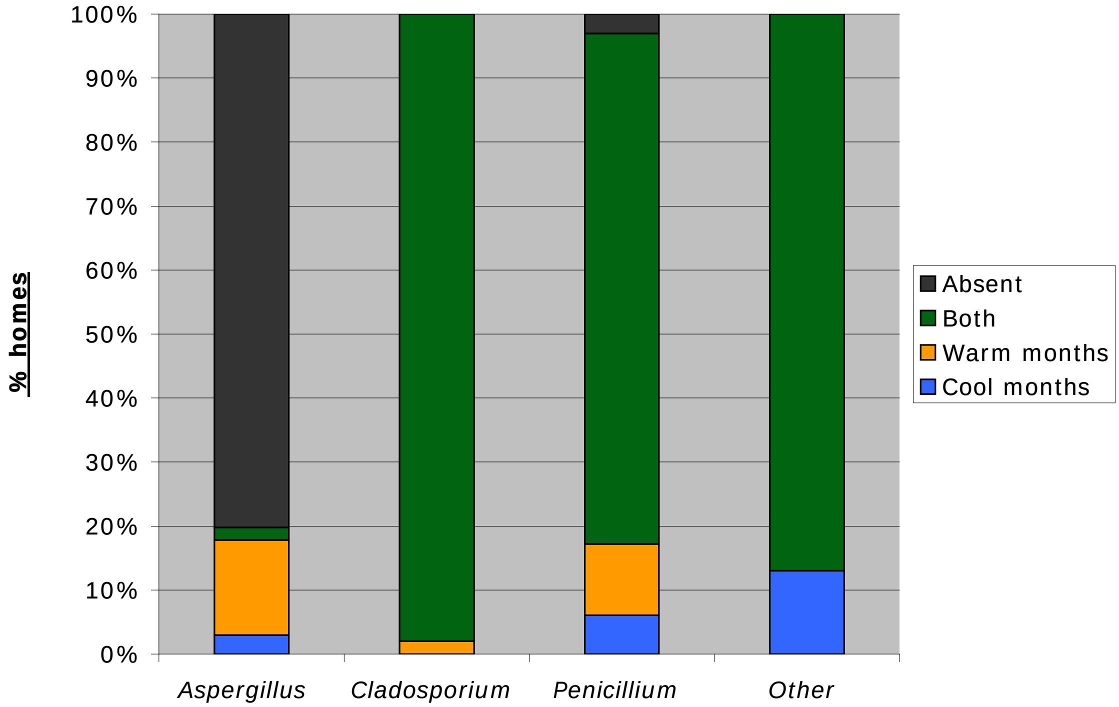
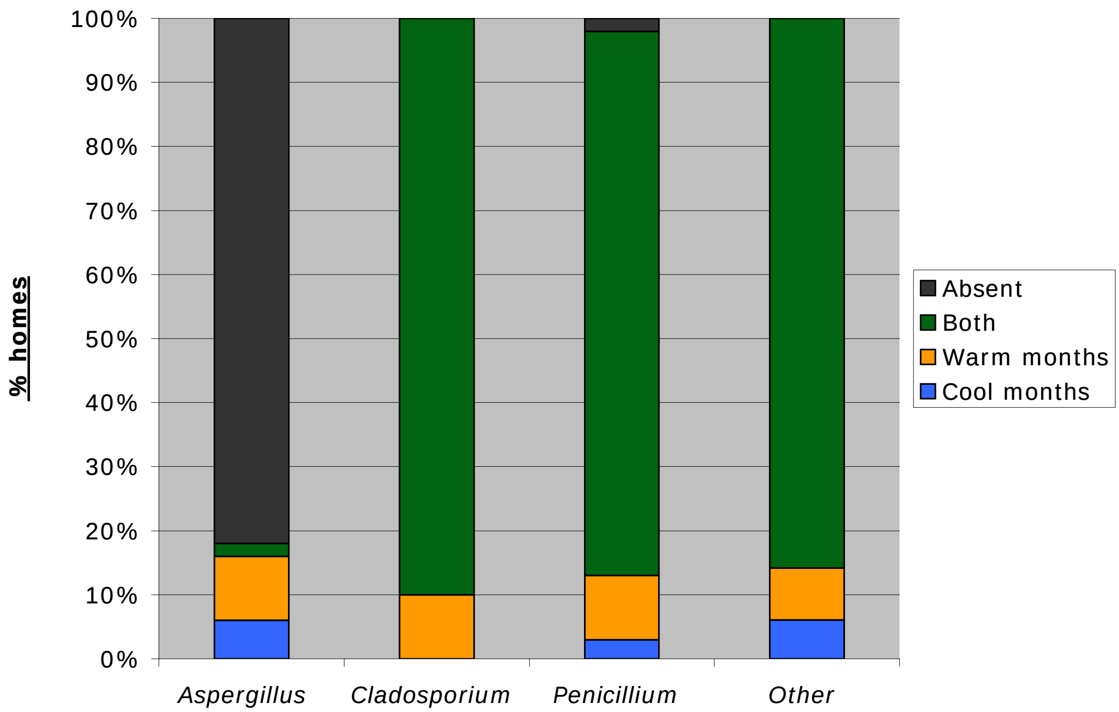



**Figure 4-4b. Detection frequency in indoor samples**



*Population Size.* The total fungal counts differed significantly across seasons for both outdoor and indoor samples (**Table 4-3**). The total fungal counts in the outdoor samples, on average, were 51 percent higher in the warm months when comparing means and 102 percent higher when comparing medians. Not surprisingly, the Wilcoxon matched pairs signed rank test comparing total fungal counts between warm months and cool months was highly significant and negative, indicating that total outdoor fungal counts were significantly higher in the warm months than in the cool months. The same holds for fungal counts for the *Aspergillus*, *Cladosporium*, and *Penicillium* groupings. For the "Other" grouping, however, fungal counts are higher in the cool months than in the warm months, but the difference is not statistically significant.

**Table 4-3. Summary measures of fungal counts across seasons (CFU/m$^3$) and results of Wilcoxon signed rank test.**

| | Cool months | | | Warm months | | | Z | p |
|---|---|---|---|---|---|---|---|---|
| | Mean (median) | Min | Max | Mean (median) | Min | Max | | |
| **Outdoor** | | | | | | | | |
| Total count | 2808 (1039) | 10 | 11756* | 4251 (2100) | 373 | 11756* | -3.20 | 0.001 |
| *Aspergillus* | 0.67 (0) | 0 | 22 | 64 (0) | 0 | 2939 | -2.39 | 0.017 |
| *Cladosporium* | 610 (122) | 0 | 5290 | 2211 (1124) | 34 | 11286 | -5.19 | <0.001 |
| *Penicillium* | 91 (37) | 0 | 1528 | 353 (116) | 0 | 5878 | -4.33 | <0.001 |
| Other | 2106 (510) | 10 | 11638 | 1627 (233) | 0 | 11521 | 0.68 | 0.500 |
| **Indoor** | | | | | | | | |
| Total count | 1233 (325) | 10 | 11756* | 1155 (846) | 113 | 5468 | -2.65 | 0.008 |
| *Aspergillus* | 0.87 (0) | 0 | 13 | 2.9 (0) | 0 | 40 | -1.01 | 0.3131 |
| *Cladosporium* | 182 (59) | 0 | 4115 | 561 (294) | 20 | 5140 | -5.68 | <0.001 |
| *Penicillium* | 59 (29) | 0 | 495 | 136 (61) | 0 | 1032 | -3.24 | 0.001 |
| Other | 991 (164) | 0 | 11521 | 460 (135) | 0 | 4788 | 0.81 | 0.418 |

* 11756 cfu's is the maximum detectable fungal count for the sampling methodology we employed. Actual fungal counts could have been higher.

The total fungal counts in the indoor samples, on average were 6 percent lower in the warm months when comparing means but 160 percent higher when comparing medians. The Wilcoxon matched pairs signed rank test was highly significant and negative, indicating that total indoor fungal counts were significantly higher in the warm months than in the cool months. The fungal counts for *Cladosporium* and *Penicillium* were significantly higher in the warm months; differences in counts across seasons for *Aspergillus* and "Other" were not significant in the indoor samples.

*Community composition.* Examining the trends in the composition of the outdoor fungal community, we found that *Cladosporium* dominated in the warm months, while species in the "Other" grouping dominated in the cool months (**Figure 4-5**); these differences across seasons were statistically significant. The proportion of the total fungal count accounted for by

*Penicillium* did not differ significantly across seasons (z=0.46, p=0.64), while the proportion of *Aspergillus* was significantly greater in the warm months (z=2.29, p=0.02). The indoor community showed the same general trends (**Figure 4-6**), except that the proportion of *Aspergillus* did not differ significantly across seasons (z= 0.79, p=0.27).

**Figure 4-5. Median composition of outdoor fungal community across seasons (NB: Both *Aspergillus* median values were zero and thus left off the figure; the distributions did differ significantly across seasons, p=0.02). Columns with different letters differ significantly, p< 0.05.**

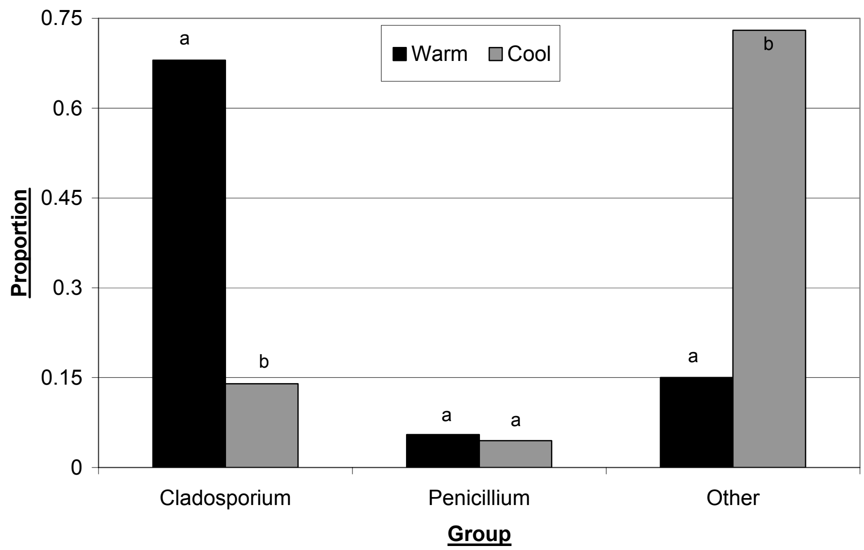
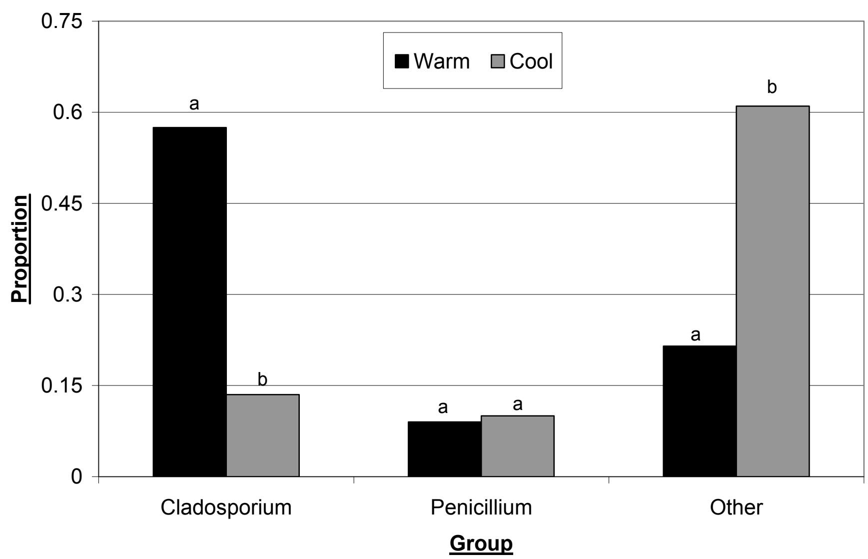



**Figure 4-6. Composition of indoor fungal community across seasons (NB: *Aspergillus* was left out as its median values were zero; the distributions did not differ significantly across seasons, p>0.1). Columns with different letters differ significantly, p< 0.05.**



*Fungal growth correlations.* When examining the correlation between outdoor counts in the warm months and those in the cool months (**Table 4-4**), only total fungal counts revealed a significant positive, albeit weak, correlation across seasons ($r_s$=0.27; p=0.03). None of the correlations for the fungal groupings were significant. When examining the correlation between indoor counts in the warm months and those in the cool months, neither the total nor the fungal groupings correlations were significant.

**Table 4-4. Spearman rank correlation of indoor and outdoor fungal counts across seasons.**

| Grouping | Outdoor | | | Indoor | | |
|---|---|---|---|---|---|---|
| | N | $r_s$ | p-value | N | $r_s$ | p-value |
| Total fungal count | 62 | 0.27 | 0.03 | 62 | 0.22 | 0.98 |
| *Aspergillus* | 12 | NA | NA | 11 | NA | NA |
| *Cladosporium* | 61 | 0.22 | 0.91 | 62 | 0.22 | 0.99 |
| *Penicillium* | 60 | 0.22 | 0.98 | 58 | 0.19 | 0.99 |
| Other | 62 | 0.25 | 0.85 | 62 | -0.06 | 1.00 |

NB: paired zeros excluded from analysis

In contrast, when examining the correlation between indoor and outdoor counts within a given season (**Table 4-5**), total fungal counts, *Cladosporium*, and “Other” were significantly correlated during the cool months. Only the “Other” grouping was significantly correlated during the warm months.

**Table 4-5. Spearman rank correlation of indoor and outdoor fungal counts across seasons.**

| Grouping | Cool months | | | Warm months | | |
|---|---|---|---|---|---|---|
| | N | $r_s$ | p-value | N | $r_s$ | p-value |
| Total fungal count | 62 | 0.73 | <0.001 | 62 | 0.35 | 0.22 |
| *Aspergillus* spp. | 6 | 1.00 | 1.00 | 14 | 0.14 | 1.00 |
| *Cladosporium* spp. | 61 | 0.57 | <0.001 | 62 | 0.32 | 0.38 |
| *Penicillium* spp. | 58 | 0.36 | 0.40 | 62 | 0.39 | 0.16 |
| Other | 62 | 0.76 | <0.001 | 59 | 0.64 | <0.001 |

NB: paired zeros excluded from analysis

### *4.2.3 Significance*

Our analysis demonstrates strong seasonal variation in indoor airborne fungi with implications for the assessment of indoor health risks in the Southeastern United States. We found that total indoor fungal counts were twice as high during the warm months than during the cool months. Additionally, the size and frequency of indoor *Cladosporium* populations, a common allergen, were also significantly greater during the warm months. Thus, in the Southeast, it would be important to assess indoor fungal communities in the context of health risks during the warm months, as that is when most of the common allergens and overall fungal levels are at their highest.

The likely explanation for the greater abundances and frequencies of fungi during the warm months lies in the associated higher relative humidity and temperature, which is consistent with other studies that have commented on the relationship between fungal growth and high humidity and temperature levels [4,7,10-12]. Again, consistent with other studies, *Penicillium* and *Aspergillus* did not follow these trends. Fungal counts for *Penicillium* did not differ significantly across seasons, suggesting that neither outdoor nor indoor *Penicillium* populations are substantially affected by seasonal variation in ambient conditions. Indoor populations of *Aspergillus* exhibited the same lack of seasonal difference; however, outdoor populations were significantly greater in the warm months, suggesting that *Aspergillus* (as compared to *Penicillium*) may be more sensitive to changes in ambient conditions outdoors.

Since several studies have indicated that outdoor fungal levels often drive indoor levels [10,11,13], we also investigated if and how the relationship between outdoor and indoor fungal communities changed in our study area. Our correlation analysis comparing outdoor and indoor fungal communities showed significant moderate to strong positive correlations for total fungal counts and for *Cladosporium* and "Other" during the cool months; however, during the warm months, we only detected a significant correlation for the "Other" grouping. This suggests that in the Southeast, the indoor and outdoor fungal communities are associated much more so in the cool months, with the larger outdoor community likely driving the indoor community.

The stronger correlations in the cool months as well as the larger differences between the outdoor and indoor communities in the warm months reflect the differences in the factors supporting fungal growth between the two seasons. Studies from the Northeast and Canadian regions found strong correlations between the indoor and outdoor fungal communities during the warm months and explained them with the typical behavior of keeping windows open during warm months [10,13]. However, many homes in our study (and in the Southeast in general) use air conditioning continuously during the warm months. Thus homes in our study area are more likely closed up during the warm months, when outdoor temperature and humidity levels are high. Conversely, given the milder climate in the Southeast, residents likely leave windows and doors open more often (as compared to residents in colder climates) during the cool months. Thus our study of Southeastern homes indicates that fungal abundances and communities are quite variable across seasons and behave differently from results observed in other climates.

The studies in the Northeast and Canada by Ren and others and Li and Kendrick [10,13] found that indoor communities of *Aspergillus* and *Penicillium* were larger than the outdoor communities (NB: Li and Kendrick lumped *Aspergillus* and *Penicillium* into one group). Results from both studies also suggested more favorable conditions indoors for both genera during the winter months and no clear trends for the outdoor communities. In contrast, our results suggest some differences in these two genera for our study area. We did not find larger populations of either genus indoors; indeed, the medians for all seasons were always larger for the outdoor communities. *Aspergillus* also had a higher frequency outdoors in the growing season. Thus, while these two genera seem to be important for the indoor winter fungal communities in the Northeast and less dependent on their outdoor counterparts, their populations in North Carolina are more important for the summer communities and more closely tied to the outdoor community.

For 17 cases, we also identified *Basidiomycetes* and *Mycelia sterilia*, in addition to the three genera mentioned earlier. These findings suggest that *Basidiomycetes* are an important component of the cool month fungal communities in the Southeast both indoors and outdoors; *Mycelia sterilia*, in contrast, is a more minor component of the fungal community, and primarily during the warm months. Identification of these two taxa is important, as both have potential health effects. *Basidiomycetes* species have been identified as allergens [14,15] and have been associated with asthma and other upper respiratory tract diseases [15-18]. Elevated levels of *Mycelia sterilia* have been associated with children complaining of wheeze in a study in England [6].

## 4.3 Bioaerosols in the Home Environment

This part of the study was designed to assess the ambient exposure to airborne fungi in the home environment. Airborne fungal spores, particularly those from the genera *Aspergillus*, *Cladosporium*, and *Penicillium* are well known allergens and asthma triggers[4,8,19], while *Mycelia sterilia* are also known respiratory irritants [6]. This analysis draws on 551 homes sampled in 2001 to 2004.

### *4.3.1 Bioaerosol Sampling Methodology*

Bioaerosol sampling proceeded as described in **Section 4.1.1**. Once fungal counts and speciation were completed, we flagged homes (BA flag) for a bioaerosol problem if at least one of the following conditions applied:

1) Total indoor fungal count exceeded 1000 CFU;
2) Indoor fungal count was greater than the outdoor fungal count; or
3) The rank order of the indoor fungal community differed significantly from the outdoor community.

We used log-linear models to analyze the environmental, demographic, and house-level factors associated with the levels of bioaerosols in the indoor environment. The exception to this analysis was *Aspergillus*, which, due to low detection rates, was better suited for analysis using a logistic model. We also used logistic models to analyze the homes with BA flags to determine the factors associated with indoor bioaerosol problems. We used STATA 9.0 for our analysis and used an *alpha* value of 0.05.

### *4.3.2 Findings*

Our study revealed significant differences in fungal counts across regions in North Carolina. Total fungal counts on the Coast were significantly lower both indoors and outdoors than on the Piedmont and Coastal Plain (**Figure 4-7**). The results for *Cladosporium* followed a similar trend: it represented a smaller portion of both indoor and outdoor fungal communities on the Coast compared to the other two regions (**Figure 4-8**). In contrast, we found mean indoor *Penicillium* levels to be significantly higher on the Coast; outdoor levels were also higher on the coast, albeit not significantly (**Figure 4-9**). Further, the percent *Penicillium* was greater indoors than outdoors, suggesting *Penicillium* plays a more significant role in the indoor community. *Mycelia sterilia* were generally significantly lower on the Coastal Plain indoors and outdoors, although the indoor levels on the Coast did not differ significantly from the Coastal Plain (**Figure 4-10**). In the Piedmont and Coastal Plain, *Mycelia sterilia* indoor levels generally exceeded outdoor levels. Our grouping of “Other” species showed no significant variation across region (**Figure 4-11**). The analysis of *Aspergillus* requires a slightly different approach, as it is found infrequently and at very low levels (the median level in our study was 0 CFU). **Figure 4-12** portrays the detection frequency found in our study for *Aspergillus*. A 3-sample median test did not reveal any significant variation in indoor levels across regions. Nonetheless, homes in both the Coastal Plain and on the Coast had detectable *Aspergillus* spores indoors more frequently than outdoors.

**Figure 4-7. Geometric mean of total fungal count by region (columns with different letters represent significant differences across region, p ≤ 0.05).**

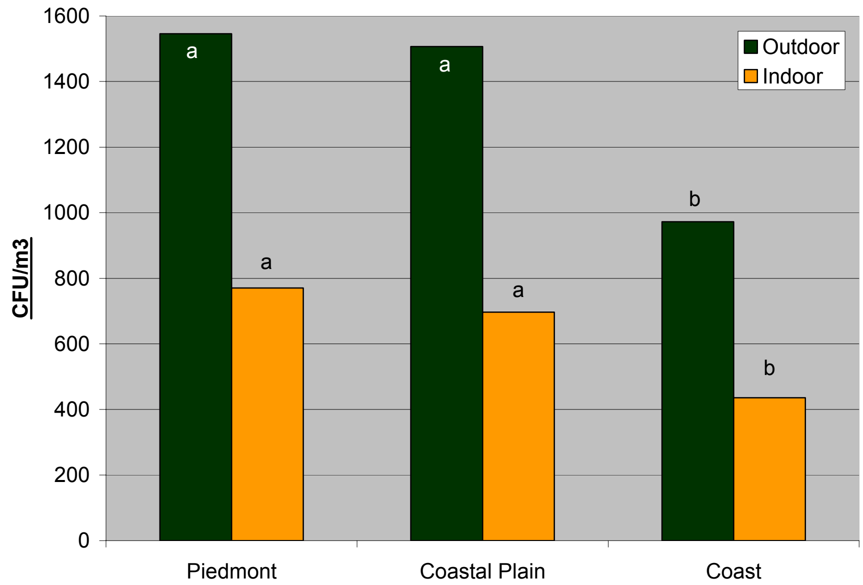



**Figure 4-8. Average percent *Cladosporium* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05).**

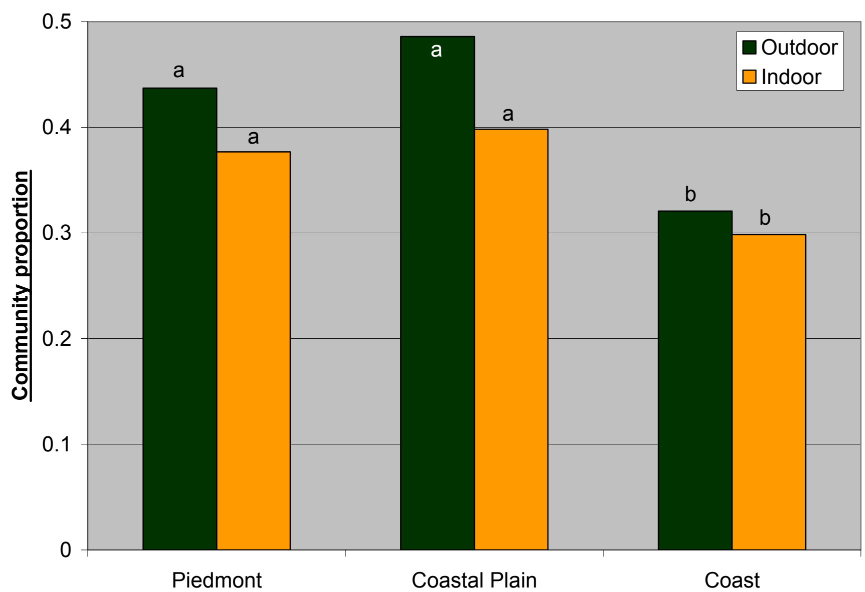


**Figure 4-9. Average percent *Penicillium* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05).**

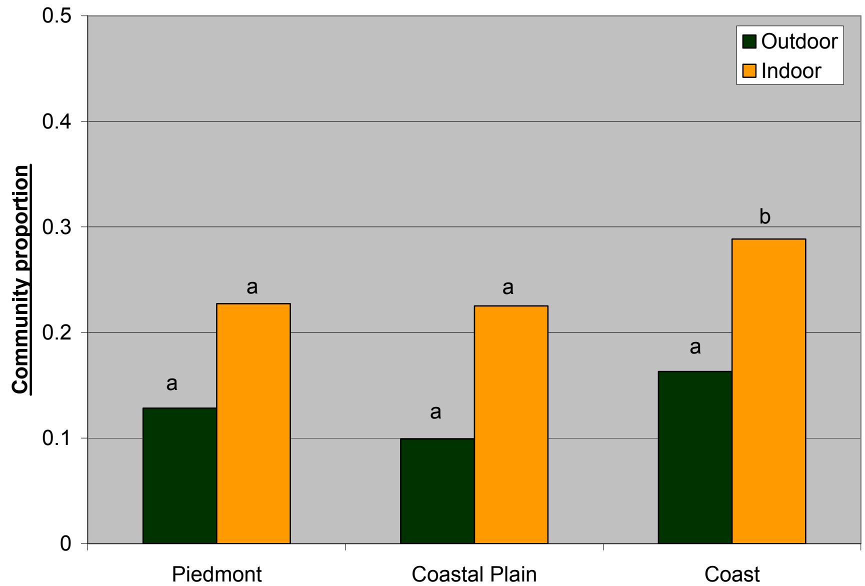



**Figure 4-10. Average percent *Mycelia sterilia* in fungal community by region (columns with different letters represent significant differences across region, p ≤ 0.05).**

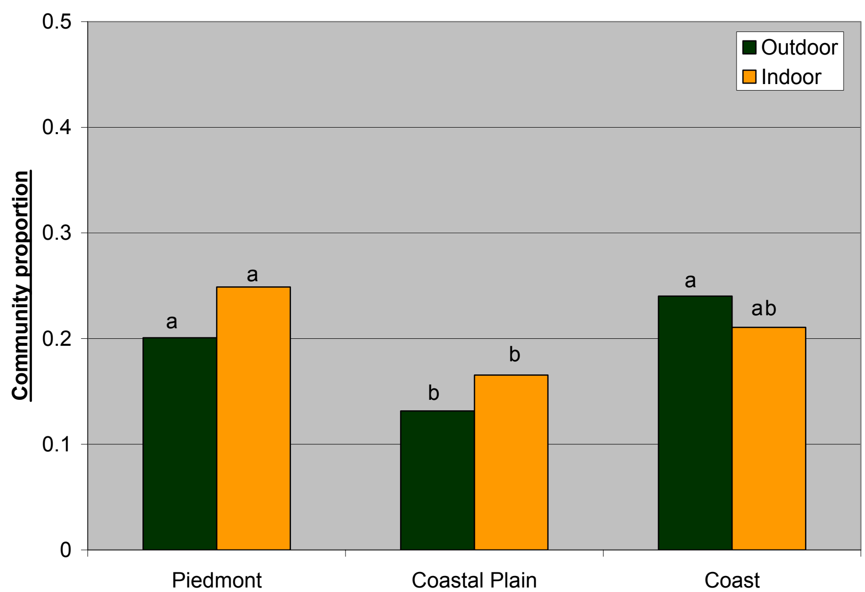


**Figure 4-11. Average percent Other species in fungal community by region (columns with different letters represent significant differences across region, $p \leq 0.05$).**

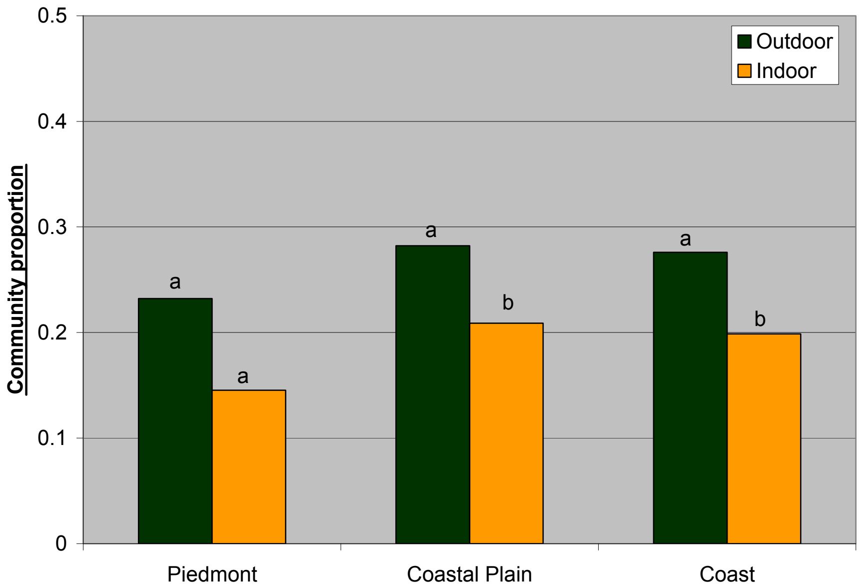
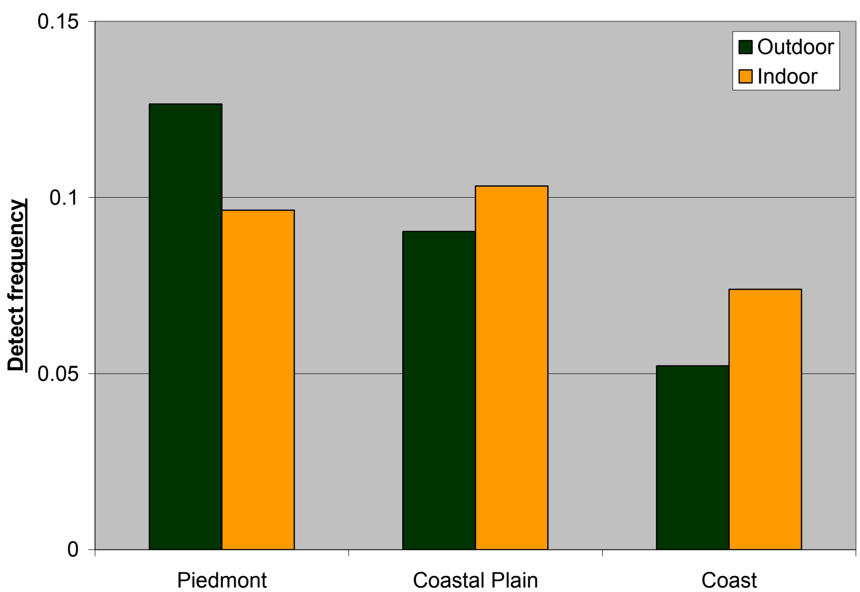
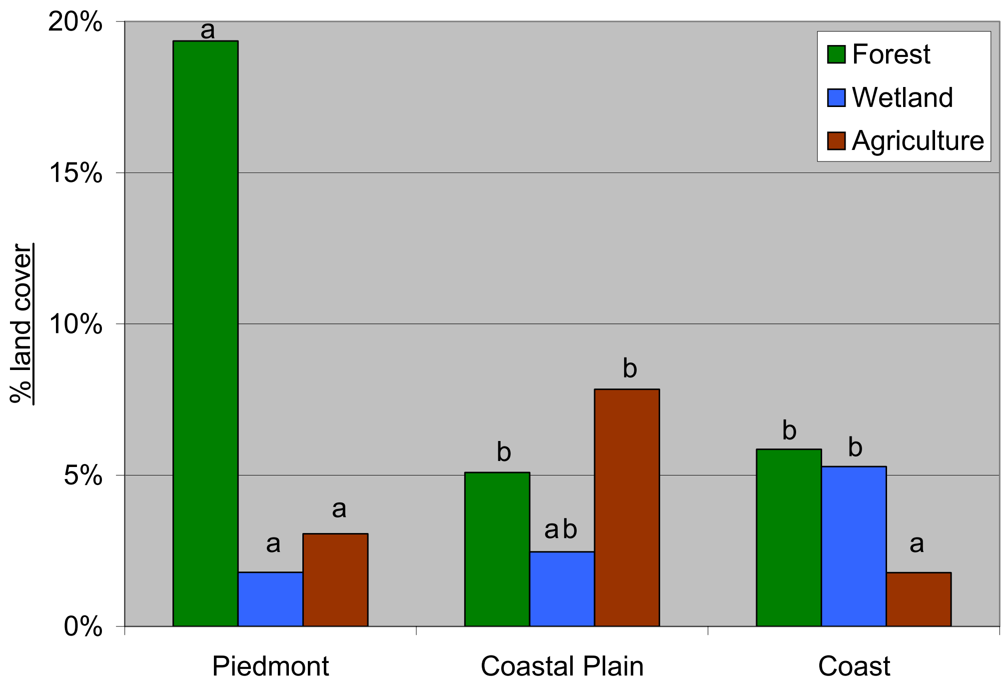



**Figure 4-12. Detection frequency of *Aspergillus* by region.**



One explanation for the regional variation in fungal levels lies in the land cover of regions. **Figure 4-13** shows the mean percent land cover of three different land cover types (forest, agriculture, and wetland) within a 500 meter radius of the study homes. Much of the land surrounding the homes did not fall into one of these categories and thus represents developed land. Using a one-way ANOVA with *post-hoc* Sidak comparisons, we found significant differences for each land type across our three regions. The homes in the Piedmont had much higher percentages of forest surrounding their homes compared to the other regions ($F(153)=17.65$, $p<0.001$). The homes in the Coastal Plain had significantly higher levels of agricultural land nearby compared to the other regions ($F(153) = 4.36$, $p=0.015$). The homes on the Coast were surrounded by higher levels of wetlands than the Piedmont homes ($P(153) = 5.93$, $p=0.004$); the mean percent wetlands was also higher than the homes on the Coastal Plain, although the difference was borderline significant ($p=0.07$). We investigate the relationship between land cover and fungal levels more closely in the section below.

**Figure 4-13. Mean percent land cover within 500 m radius of home. Different letters indicate significant differences (p < 0.05) across regions for individual land cover types.**




We found significant associations for various environmental, demographic, and house-level characteristics with indoor fungal counts (**Table 4-6** and **Figure**s **4-14a** and **b**). Among the environmental variables showing up in our models, the most consistent was a strong positive relationship with the corresponding outdoor measure (**Table 4-7**). This demonstrates the role the outdoor fungal community generally plays in shaping the indoor community. Another major influence was the climate, as demonstrated by the results from the Palmer Drought Index (PDI). The PDI, where higher values reflect greater moisture availability, showed a positive significant relationship with all but *Cladosporium* fungal counts. Several landscape characteristics also were important in individual models, although at borderline significant levels: percent forest cover within 500 m of a home had a positive relationship with total fungal counts; percent wetland within 500 m of a home had a positive relationship with *Penicillium* fungal counts; and distance to 100 year floodplain had a positive relationship with *Cladosporium* fungal counts.

**Table 4-6. Significant variables in the bioaerosol models.**

| Variable | Description | log-transformed |
|---|---|---|
| **Environmental** | | |
| PDI | Weekly Palmer drought index (PDI) for region. Lower numbers reflect drought conditions. | no |
| Percent agriculture | Percent agricultural land in 500 m around parcel | yes |
| Percent forest | Percent forested land in 500 m around parcel | yes |
| Distance to 100 year floodplain | Distance from center of parcel to closest 100 year floodplain | yes |
| Percent wetland | Percent wetland in 500 m around parcel | yes |
| **Demographic** | | |
| Urban | Dummy variable based on block data from Census 2000, urban = 1 | |
| % African-American | % African-American in block; based on data from Census 2000 | yes |
| Household Median Income | Median income for households in blockgroup; based on data from Census 2000 | yes |
| **House-level** | | |
| Spanish survey | Dummy variable: participant completed survey in Spanish = 1 | no |
| Year built | Tax parcel data for year home was built | no |
| Rent | Dummy variable: participant reported water leak had occurred in home =1 | no |
| Crawlspace | Dummy variable: home has crawlspace = 1 | no |
| Musty odor | Dummy variable: participant reported very musty odor in home = 1 | no |
| Dehumidifier | Dummy variable: participant reported using dehumidifier at least occasionally =1 | no |
| Carpeted Home | Dummy variable: participant reported home was fully carpeted = 1 | no |

**Table 4-7. Coefficients of significant environmental factors associated with fungal counts in the home environment (Figures in *italics* had a p-value between 0.05 and 0.10).**

| Fungal count ($CFU/m^3$) | $CFU_{outdoors}$ | PDI | % forest | % wetland | dist. to100-yr floodplain |
|---|---|---|---|---|---|
| ln(TOTAL) | 0.326 | 0.176 | *0.576* | NS | NS |
| ln(CLAD) | 0.437 | NS | NS | NS | *0.045* |
| ln(PEN) | 0.321 | 0.212 | NS | *1.97* | NS |
| ln(MS) | 0.515 | 0.127 | NS | NS | NS |
| ln(Other) | 0.281 | 0.24 | NS | NS | NS |
| logit ASP | 2.14 | 0.166 | NS | NS | NS |

NS: not statistically-significant

**Figure 4-14a. Relationship between total indoor fungal count ($CFU/m^3$) by land cover and distance to floodplain in Durham County, NC.**

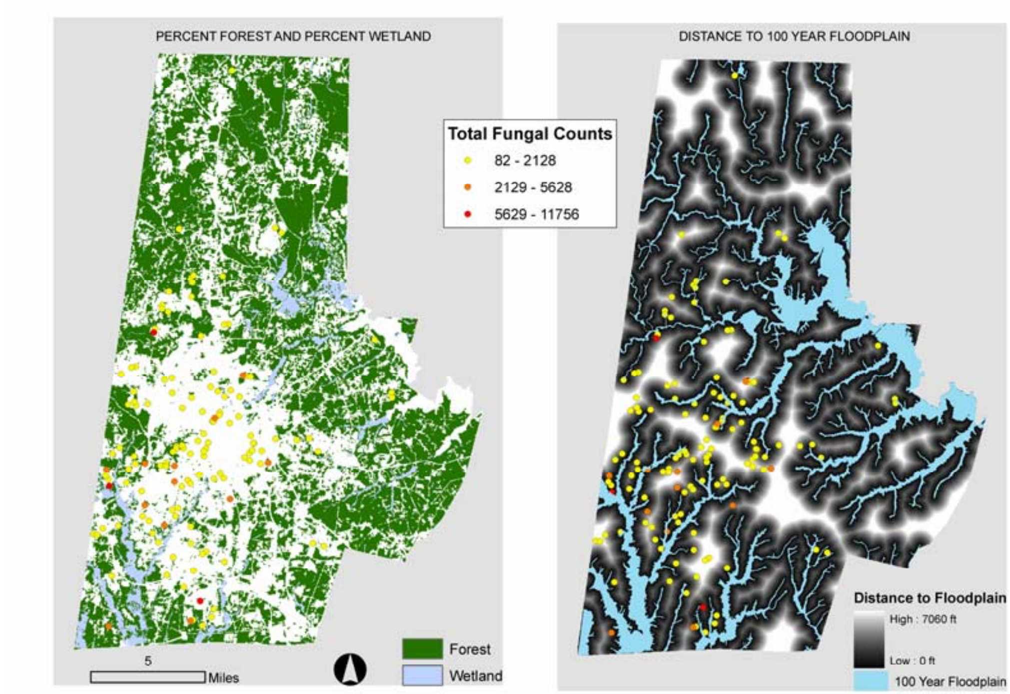
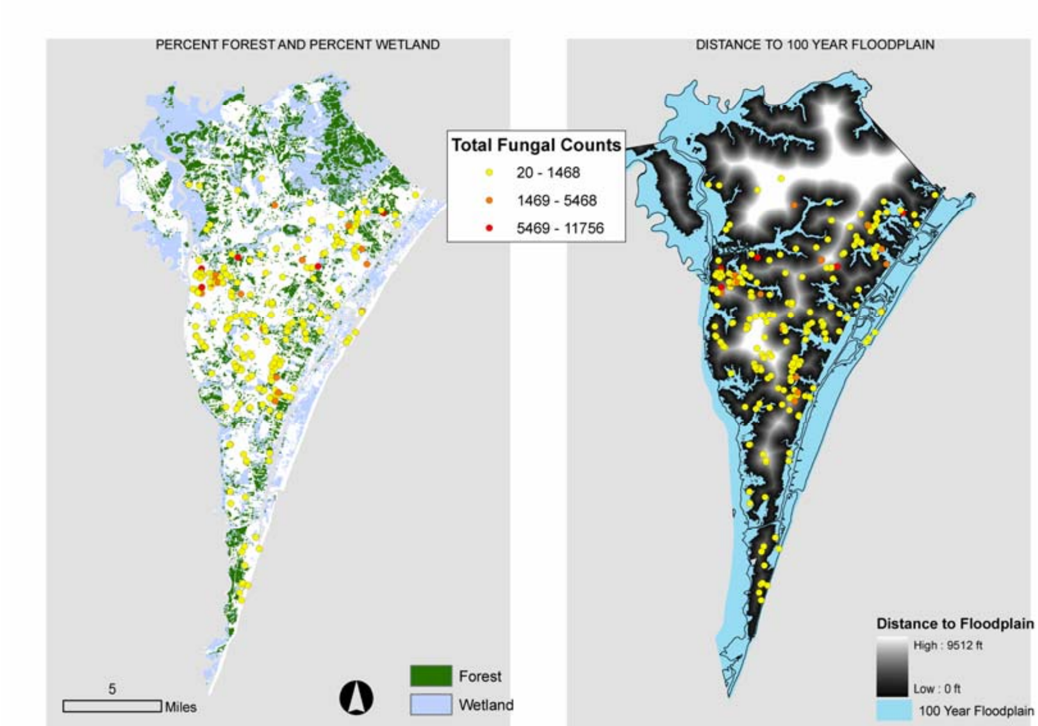


**Figure 4-14b. Relationship between total indoor fungal count (CFU/m$^3$) by land cover and distance to floodplain in New Hanover County, NC.**




Our sampling also revealed a distinct effect of sampling year, reflecting the often drastic climate trends from year to year (**Table 4-8** and **Figure 4-15**). Using 2004 as our base year, which corresponds to a "normal" weather year, as well as to our greatest sampling effort, we generally found lower levels of total fungal counts in 2001 and 2003, which were drier than normal years. *Cladosporium* was only lower during 2001, whereas *Penicillium* was lower in both 2001 and 2003. *Mycelia sterilia* was lower in every year, compared to 2004, with 2001 showing much lower levels than 2002 and 2003. The "Other" group showed higher levels in 2001 and 2002, suggesting species included in that group respond differently to weather conditions. Indeed, this reflects findings in the analysis of seasonal variation, where groups like *Basidiomycetes*, a very common member of this "Other" category, thrive during the winter months in both the indoor and outdoor community. We did not detect any annual variation in the levels of *Aspergillus*, although any variation would be difficult to detect, given the low overall levels of this genus in our samples.

**Figure 4-15. Average temperature and precipitation for Eastern and Central NC during sampling season by sampling year (source: NWS data).**

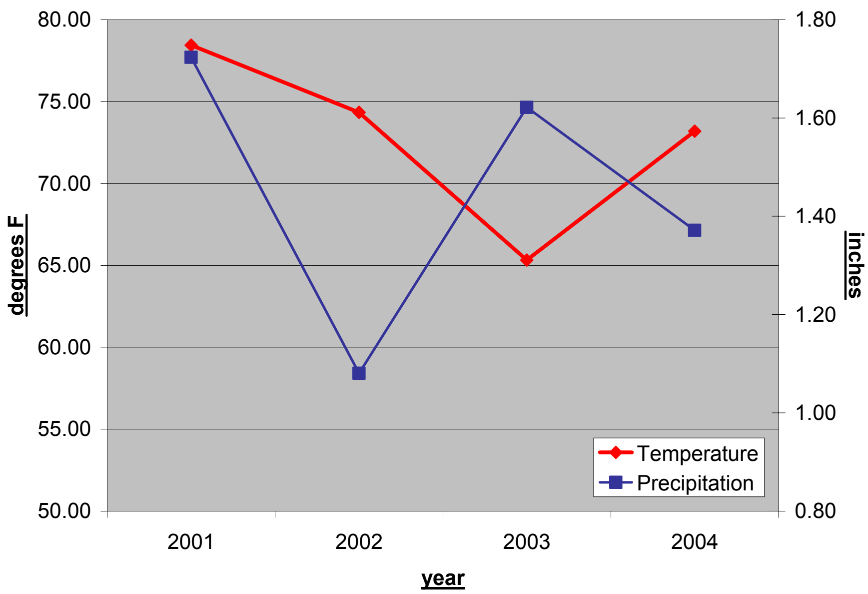



**Table 4-8. Coefficients from abundance models, reflecting effect of sampling year on indoor bioaerosol levels.**

| Variable | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|
| ln(CFU) | -0.706 | NSD | -0.553 | base |
| ln(CLAD) | -0.939 | NSD | NSD | base |
| ln(PEN) | -1.118 | NSD | -0.658 | base |
| ln(MS) | -1.97 | -0.964 | -0.875 | base |
| ln(Other) | 0.862 | 1.05 | NSD | base |
| logit ASP | NSD | NSD | NSD | base |

NSD= no significant difference from base year

Our analysis also revealed that several demographic factors also had significant relationships with indoor fungal counts (**Table 4-9a**). Spanish-speaking households (identified as those participants who completed the home survey in Spanish) tended to have greater levels of *Cladosporium* and lower levels of *Mycelia sterilia*. Homes in Census blocks with higher percentages of African-Americans also tended to have higher amounts of *Cladosporium*, while homes in urban areas (as defined by the US Census) tended to have lower amounts of *Cladosporium*. Homes in Census blockgroups with higher median household incomes had a greater likelihood of having detectable levels of *Aspergillus.*

We identified several home-level factors that related to indoor fungal levels (**Table 4-9a**). The year a home was built had a significant negative relationship with all fungal measures, except for *Aspergillus*, which indicates that newer homes generally have lower airborne fungal burdens. The relationship with year-built provides an explanation for the lower overall fungal counts observed on the Coast, as homes in that region are generally younger (Table 4-9b). The presence of a crawlspace also seemed to correspond positively with higher fungal levels in most cases; the exceptions being *Aspergillus* and *Mycelia sterilia*. Renter-occupied homes tended to have higher levels of overall airborne fungi and *Cladosporium*. The use of a dehumidifier had a negative relationship with *Penicillium* levels. Lastly, homes where residents reported a "very musty" odor had a much greater likelihood of having detectable *Aspergillus* levels.

**Table 4-9a. Coefficients of significant demographic and household factors associated with fungal counts in home environment (Figures in italics had a p-value between 0.05 and 0.10).**

| Fungal count (CFU/m$^3$) | Spanish survey | % African-American | Median Household Income | Urban | Year-built | Rent | Crawl-space | Dehumid-ifier | Musty odor |
|---|---|---|---|---|---|---|---|---|---|
| ln(TOTAL) | NS | NS | NS | NS | -0.0055 | 0.395 | 0.237 | NS | NS |
| ln(CLAD) | 0.697 | 0.087 | NS | *-0.323* | -0.0058 | 0.318 | 0.294 | NS | NS |
| ln(PEN) | NS | NS | NS | NS | -0.0098 | NS | 0.373 | *-0.403* | NS |
| ln(MS) | *-0.689* | NS | NS | NS | -0.0061 | NS | NS | NS | NS |
| ln(Other) | NS | NS | NS | NS | -0.0085 | NS | 0.379 | NS | NS |
| ASP | NS | NS | 0.951 | NS | NS | NS | NS | NS | 1.901 |

NS: not statistically-significant

**Table 4-9b. Distribution of housing age in sampled homes, by region**

| Centile | Piedmont | Coastal Plain | Coast |
|---|---|---|---|
| Minimum | 1871 | 1865 | 1878 |
| 25th percentile | 1948 | 1952 | 1958 |
| Median | 1967 | 1970 | 1980 |
| 75th percentile | 1987 | 1985 | 1995 |
| Maximum | 2003 | 2002 | 2003 |

After flagging our homes for bioaerosol problems using the criteria mentioned above, we discovered that over 58% of our homes had a potential problem with bioaerosols (**Figure 4-16**). The Piedmont region had the greatest percentage of homes exhibiting BA flags (65%), while the Coastal Plain had the lowest (54%). The reasons behind the flags varied regionally as well (**Table 4-10**). In the Piedmont and the Coastal Plain, the greatest number of flags involved indoor fungal counts exceeding the benchmark of 1000 CFU/m$^3$. The substantially lower percentage of Coastal homes exhibiting excessive indoor fungal loads reflects the lower overall fungal levels presented in **Figure 4-7**. On the Coast, the most frequent cause of a BA flag was a rank order difference between the indoor and the outdoor fungal communities.

**Figure 4-16. Prevalence of bioaerosol flags by region.**

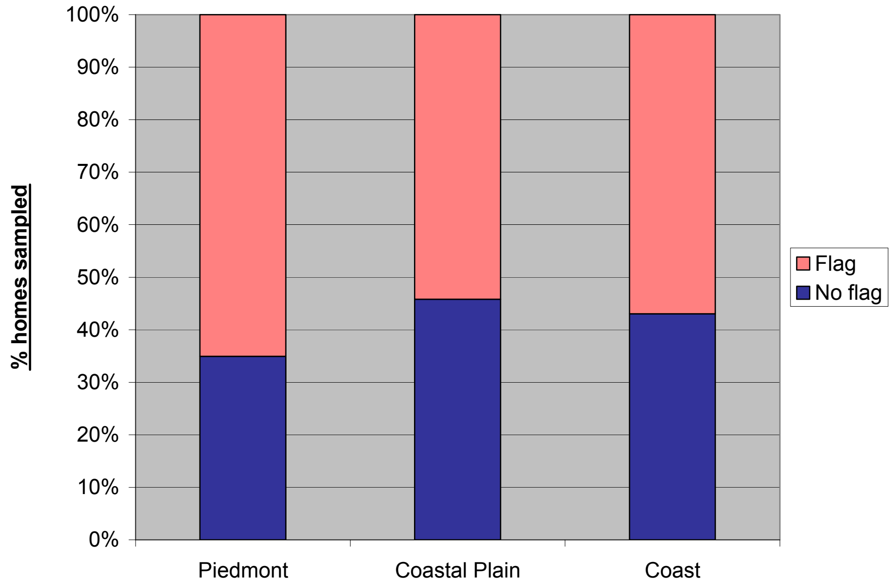



**Table 4-10. Basis for bioaerosol flags.**

| | Piedmont | Coastal Plain | Coast | Total |
|---|---|---|---|---|
| $CFU_{in}$ > 1000 | 58.3% | 58.3% | 31.3% | 47.4% |
| $CFU_{in}$ > $CFU_{out}$ | 38.9% | 35.7% | 45.8% | 40.9% |
| Rank order different | 57.4% | 53.6% | 73.3% | 62.8% |

Using logistic regression, we analyzed what factors relate to homes flagged for bioaerosol problems (**Table 4-11**). Similar to the fungal abundance models, we found a strong positive relationship with total outdoor fungal levels. We also found a strong relationship with the Palmer Drought Index, suggesting that indoor air problems are linked to favorable growing conditions for fungi outdoors. We found a positive relationship with the percent of forest surrounding a home and a similar, but negative, relationship with the percent of land in agriculture surrounding a home. This finding suggests that forested land may represent a better source for airborne fungi than agricultural land. It is unclear if this might be related to the use of fungicides on the latter. Two house-level factors also correspond with BA flags: the presence of a crawlspace and the lack of carpeting in a home. The latter relationship is curious and should be examined more closely. Although several demographic factors correlated with various measures of fungal abundance above, we did not find any demographics factors that related to BA flags. In general, it appears that environmental factors, rather than demographic factors, play a larger role for airborne fungi.

**Table 4-11. Coefficients of factors associated with indoor bioaerosol flags (Figures in *italics* had a p-value between 0.05 and 0.10).**

| | $CFU_{outdoors}$ | Drought Index | % forest | % agriculture | Crawlspace | Carpeted home |
|---|---|---|---|---|---|---|
| logit BA flag | 0.371 | 0.202 | 2.24 | -2.21 | 0.424 | *-0.356* |

## 4.4 Bulk Dust Allergens in the Home Environment

This part of the study was designed to evaluate the ambient exposure to dustborne allergens in the home environment in NC. Exposures to dust mite and cockroach allergen have been linked to the development of asthma [20]. This analysis derives from 697 homes sampled from 2001 to 2004.

### *4.4.1 Bulk Dust Sampling Methodology*

Bulk dust sampling proceeded as described in **Section 4.1.2**. Once allergen level results (Der p1, Der f1, and Bla g1) were received from Air Quality Sciences, we flagged homes (BD flag) for a bulk dust problem if any of the levels of allergens exceeded the benchmark level of concern, which we defined by the level at which there is an increased risk for sensitization (**Table 4-12**).

**Table 4-12. Criteria for flags for bulk dust allergens.**

| Allergen | Increased risk for sensitization (µg/g) | Increased risk for symptom exacerbation (µg/g) |
|---|---:|---:|
| Dust mite Der f1 | 2 - 10 | > 10 |
| Dust mite Der p1 | 2 - 10 | > 10 |
| Cockroach Bla g1 | 1 - 4 | > 4 |

We used one-way ANOVA with Sidak *post-hoc* tests on log-transformed allergen values to analyze allergen levels for significant differences across geographic regions in NC. We used log-linear models to analyze the environmental, demographic, and house-level factors associated with the levels of allergens in the indoor environment. The exception to this analysis was the cockroach allergen, Bla g1, which, due to a low detection rate (20.6%), was better suited for analysis using a logistic model. We also used a logistic model to analyze the homes with BD flags to determine the factors associated with indoor dustborne allergen problems. We used STATA 9.0 for our analysis and used an *alpha* value of 0.05 to determine statistical significance.

### *4.4.2 Findings*

Only one of the three allergens showed significant variation across geographic regions in NC, the Der p1 allergen. Der p1 had significantly higher levels in the Piedmont and Coastal Plain regions compared to the Coast ($F(694)=9.53$, $p=0.0001$). Der f1 and Bla g1 did not show any significant differences across regions. The lack of variation in the Der f1 levels reflects the fact that it is adapted to a wide range of environmental conditions [21]; less is known about Der p1, but it appears to tolerate lower humidities less well. Examining the geometric means for the allergens, we find that the mean of each allergen exceeded the benchmark level of concern in all regions (**Figure 4-17a**). An examination of the median values provides a slightly different story: Der f1 still approaches the benchmark level for each region, while the median for Der p1 and Bla g1 are well below the benchmark, demonstrating that over half of the homes in our study do not have elevated levels of these two allergens. (**Figure 4-17b**)

**Figure 4-17a. Geometric mean of allergen levels across regions (Significant differences across region noted by different letters, p≤ 0.05).**

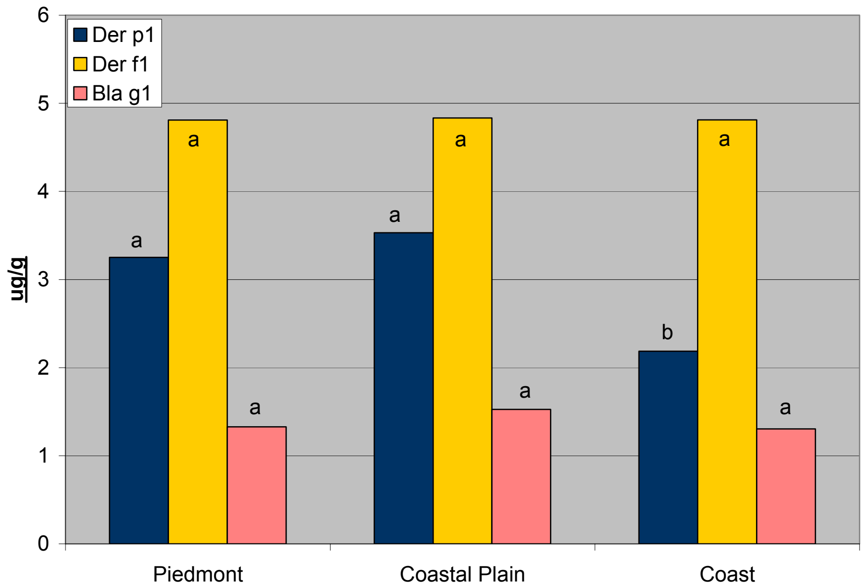
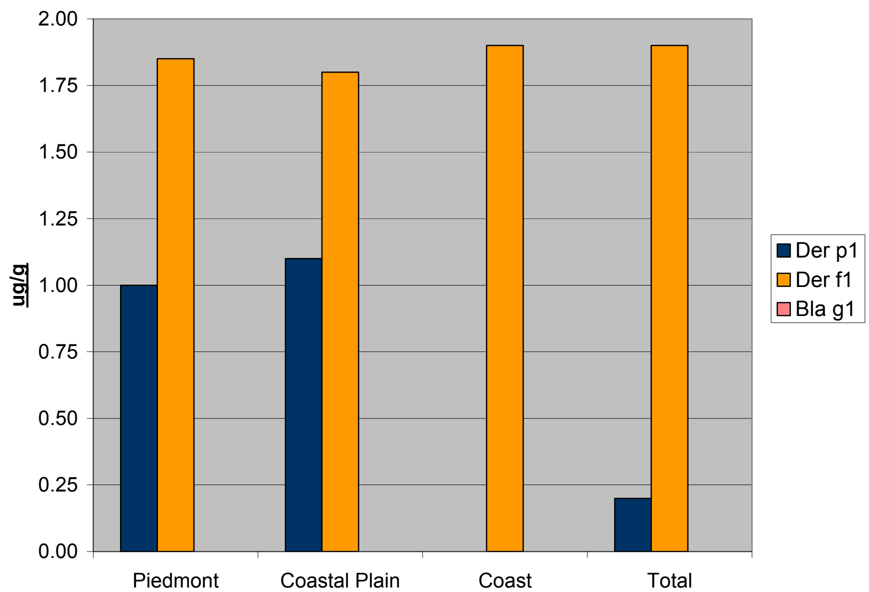



**Figure 4-17b. Median allergen levels by region (NB: Bla g1 exhibited a median value of zero across all categories; Der p1 had a median value of zero on the Coast)**




We found multiple environmental, demographic, and household-level factors related to each of the allergens. **Table 4-13** describes the variables that proved to have significant relationships with at least one of the allergens and **Figures 4-18a** and **b** show spatial relationships of some of these variables. Der p1 levels had a positive association with distance to agriculture and a negative association with distance to forest. The relationship with agriculture is unclear, although it is an indirect measure of urbanization. Forested areas typically have microclimates with higher relative humidities and thus environments more hospitable to dust mites [21]. Thus, it follows that homes closer to forested areas may have higher levels of allergens. The relationship to forest was also present in the model for the Der f1 allergen, although it was borderline significant (p=0.088). Der f1 also showed a positive relationship with our urban variable, suggesting homes in urban areas have higher levels of this allergen (**Table 4-14**).

The time when we sampled homes also impacted the levels we found in homes. Der p1 had a strong relationship with sampling month; homes sampled in May through September typically exhibited lower allergen levels compared to homes sampled in April or October. This may be due to doors and windows more commonly being open during these months in the Southeast. The coefficients for May through September did not vary significantly from each other and averaged -0.65. Der f1 and Bla g1 did not show an effect from sampling month, but, in contrast to Der p1, showed an effect from year sampled (**Table 4-15**). Der f1 levels were generally lower in homes sampled in 2002 and 2003, while Bla g1 levels were generally higher in homes sampled in 2001-2003 than in 2004.

**Table 4-13. Significant variables in allergen models.**

| Variable | Description | log-transformed |
|---|---|---|
| **Environmental** | | |
| Distance to agriculture | Distance (ft) from center of parcel to nearest agricultural land cover | yes |
| Distance to forest | Distance (ft) from center of parcel to nearest forest land cover | yes |
| **Demographic** | | |
| Urban | Dummy variable based on block data from Census 2000, urban = 1 | |
| % Hispanic | % Hispanic in block; based on data from Census 2000 | yes |
| Household Median Income | Median income for households in blockgroup; based on data from Census 2000 | yes |
| **House-level** | | |
| Carpeted Home | Dummy variable: participant reported home was fully carpeted = 1 | no |
| Water Leak | Dummy variable: participant reported water leak had occurred in home = 1 | no |
| Central AC | Dummy variable: participant reported home had central air = 1 | no |
| Year built | Tax parcel data for year home was built | no |
| Renter | Dummy variable: participant reported water leak had occurred in home =1 | no |
| Agricultural activity | Dummy variable: participant reported working in agricultural industry or gardening activity =1 | no |
| Dogs | Dummy variable: participant reported having at least one dog = 1 | no |

**Table 4-14. Coefficients for environmental and demographic factors associated with indoor dust allergen levels (Figures in italics: 0.05 < p ≤ 0.10).**

| Variable | Distance to agriculture | Distance to forest | Urban | % Hispanic | Household Median Income |
|---|---|---|---|---|---|
| ln (Der p1) | 0.096 | -0.082 | NS | NS | *0.205* |
| ln (Der f1) | NS | *-0.055* | 0.525 | *-0.098* | NS |
| logit Bla g1 | NS | NS | NS | 0.199 | NS |

**Figure 4-18a. Relationship of Der f1 levels to selected environmental and demographic variables in Wilson County, NC.**

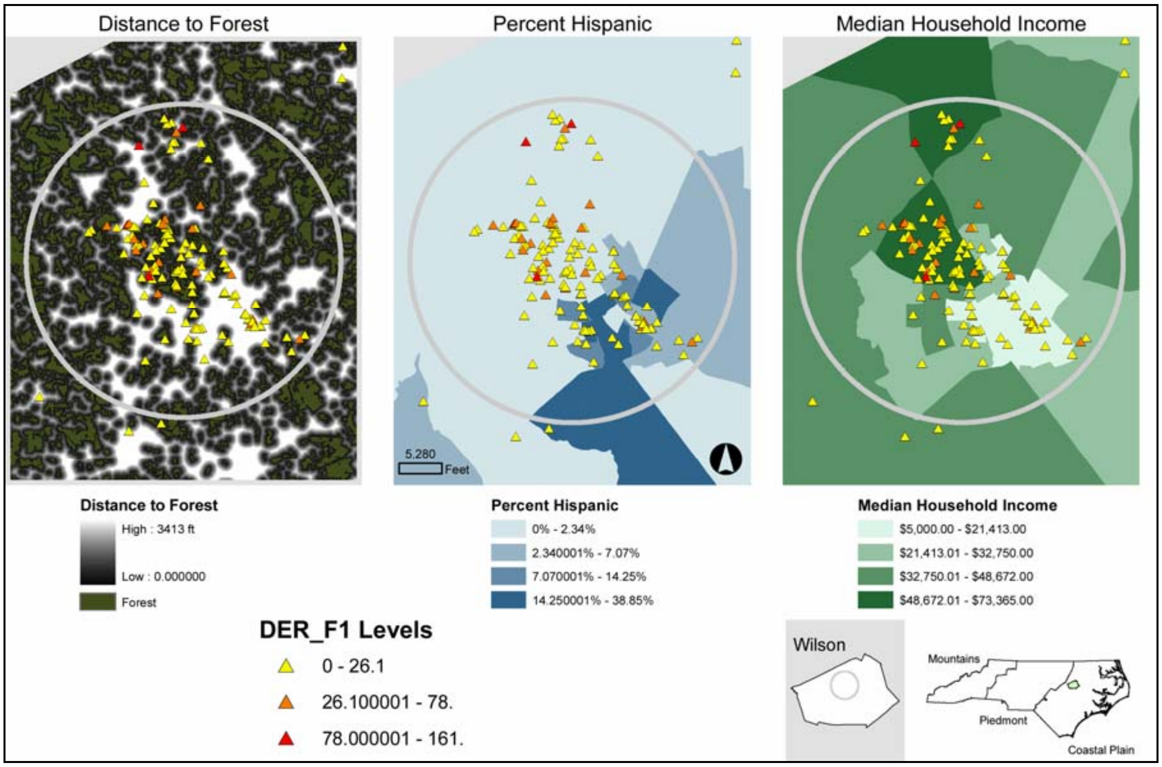


**Figure 4-18b. Relationship of Der p1 levels to selected environmental and demographic variables in Wilson County, NC.**

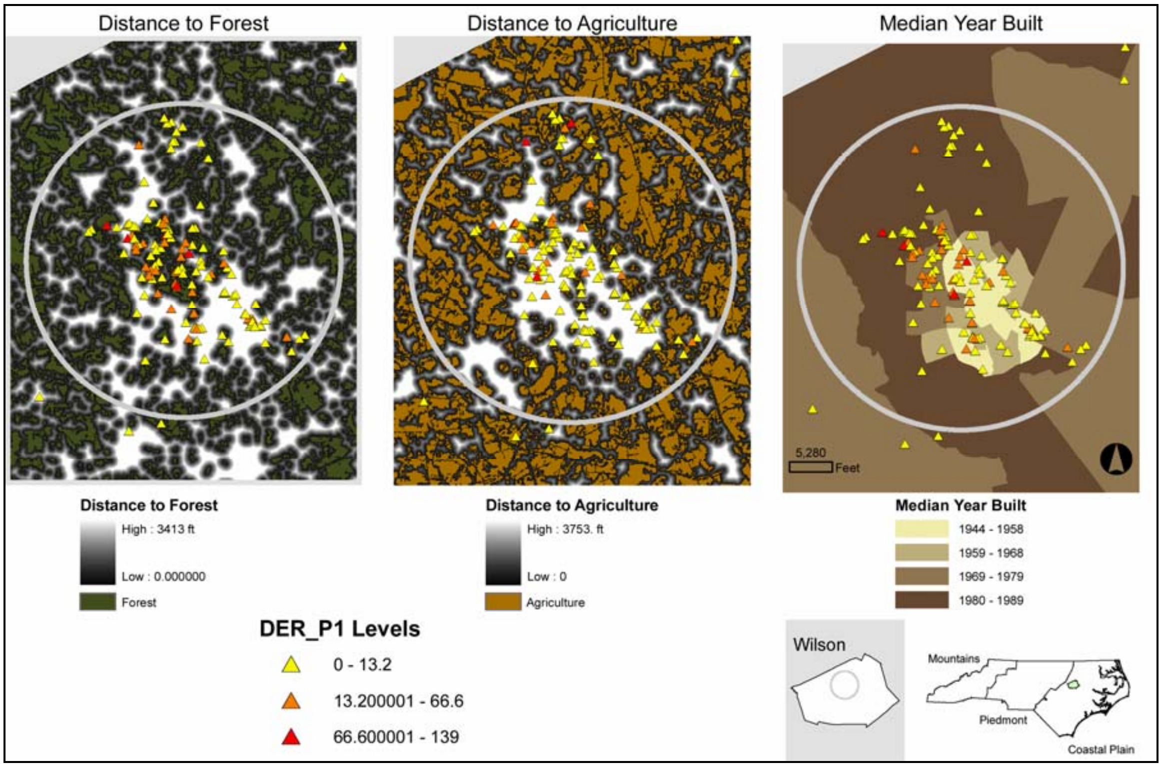



**Table 4-15. Coefficients for sampling year.**

| Variable | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|
| ln (Der p1) | NS | NS | NS | base |
| ln (Der f1) | NS | -0.553 | -0.449 | base |
| logit Bla g1 | 1.05 | 0.958 | 1.10 | base |

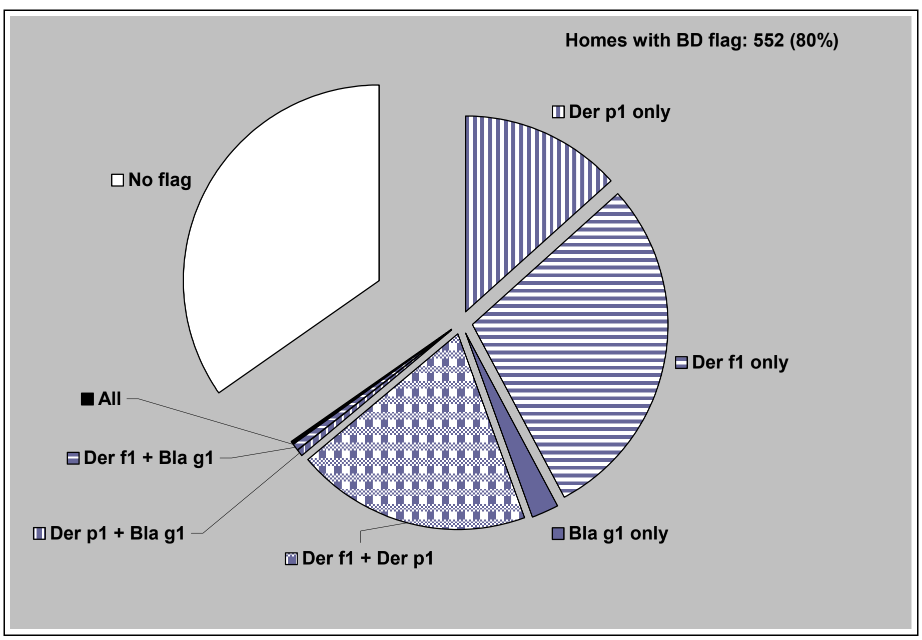
We found several house-level factors relating to home allergen levels (**Table 4-16**). Year built was significant for all allergens. Interestingly, the Der p1 showed a negative relationship with year built, while Der f1 and Bla g1 showed positive relationships. While in general, we found Der p1 and Der f1 levels to be similar, other studies have suggested that Der p1 and Der f1 allergens have different determinants, which may account for the differences in relationship with year built [22,23]. Renter-occupied homes tended to have lower levels of Der f1, but more frequent detects of cockroach allergen. Consistent with our results, van Strien et al. found that Der f1 levels were higher in houses versus apartment buildings, likely indicating a renter effect similar to our results [23]. Homes that were fully carpeted appear to have lower levels of Der p1. Generally carpets are considered to be reservoirs for dustborne allergens, so at first glance, our results appear to contradict previous studies. A closer examination of our data showed that fully carpeted homes and homes lacking carpeting had similar levels of Der p1, while homes that were partially carpeted had significantly higher levels of Der p1 ($F(691) = 3.58$; $p=0.028$). Homes with a history of water leaks or central air conditioning also tended to have higher levels of the Der p1 allergen. Homes where residents reported being involved in agriculture or gardening tended to have more frequent detects of Bla g1. We found no significant relationships between reported ownership of plush toys or upholstered furniture—factors associated with allergens in other studies. We also did not find any relationship to homes where participants reported taking measures to control dust mites.

**Table 4-16. Coefficients for house-level factors associated with indoor dust allergen levels (Figures in italics: $0.05 < p \leq 0.10$)**

| Variable | Carpeted Home | Water Leak | Central AC | Year Built | Renter | Agriculture Activity |
|---|---|---|---|---|---|---|
| ln (Der p1) | -0.268 | *0.200* | 0.37 | -0.013 | -0.432 | NS |
| ln (Der f1) | NS | NS | NS | 0.005 | *-0.336* | NS |
| logit Bla g1 | NS | NS | NS | *0.008* | 0.975 | 1.27 |

Our classification of homes for dust borne allergen problems revealed that almost 80% of our study homes have at least one allergen that exceeds benchmark levels. Most of these homes had problems with either Der p1 (34%) or Der f1 (49%), while only three percent of homes exhibited elevated levels of cockroach allergen. Of homes flagged for BD problems (**Figure 4-19**), the largest percentage had problems with only Der f1 (36%). Twenty-four percent suffered from elevated levels of both dust mite allergens, while only one home showed a problem with all three allergens.

**Figure 4-19. Causes for BD flags.**




Our logistic analysis of homes flagged for allergen problems revealed several factors influencing the flag outcome. The largest factor influencing BD flags was the year in which a home was sampled, where homes had much greater likelihoods of exhibiting an allergen problem if sampled in 2002 or 2003 (**Table 4-17**). This reflects the annual variability in allergen levels and the necessity of considering the point in time when sampling a home with potential allergen problems. Homes in urban areas also appear to be at higher risk for allergen problems; homes with full carpeting also face the same risk, although this relationship was not statistically significant (p=0.072). Several factors were negatively associated with BD flags. Homes more distant from forests as well as renter-occupied homes appear to be at lower risk for BD flags. Dog ownership also showed a possible negative association with BD flags, although this relationship was only marginally significant (p=0.055).

**Table 4-17. Odds ratios for factors related to BD flags.**

| Variable | Odds Ratio | p-value |
|---|---|---|
| year 2002 | 4.53 | 0.000 |
| year 2003 | 2.61 | 0.002 |
| Urban | 2.06 | 0.021 |
| *Carpeted home* | *1.50* | *0.072* |
| Distance to forest | 0.88 | 0.035 |
| *Dog ownership* | *0.67* | *0.055* |
| Renter | 0.44 | 0.003 |

## 4.5 Co-occurrence of Bioaerosols and Bulk Dust

Many previous studies have analyzed either the airborne or dustborne allergen load in the home environment. Building on the previous sections, this portion of the study expands the analysis to examine the joint occurrence of bioaerosol (BA) and dustborne (BD) allergens in the home environment in North Carolina. This provides a broader picture of indoor environmental health risks. This following analysis is limited to 156 homes sampled during the summers of 2003 and 2004.

### *4.5.1 Methods and Analysis*

Following the classification rules established above in sections 4.3 and 4.4 for BA and BD flags, we classified any home that received both BA and BD flags as having a joint (BABD) flag. We then analyzed the factors relating to the occurrence of BABD flags using logistic regression. We used an *alpha* value of 0.05 for all statistical analyses and used STATA 9.0 to carry out these analyses.

### *4.5.2* Findings.

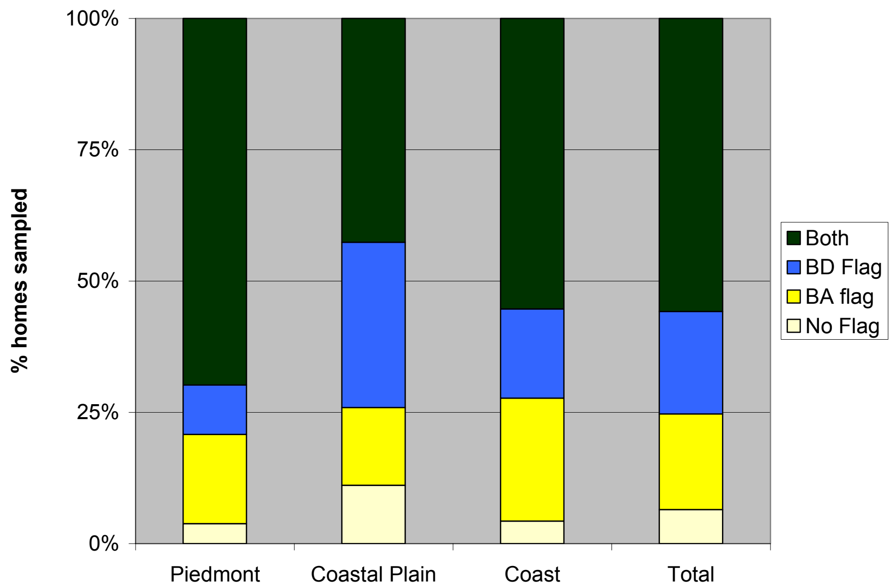
A *chi*-squared analysis found no association between bioaerosol and bulk dust allergens ($\chi 2$ = 0.003, p=0.96). Results from another study found a slight association between mold and dust mite allergen, in which concentrations of Der p1 and Der f1 were approximately 1.4 times higher in moldy homes than non-moldy homes [23]. We found that only 10 homes (6.5% of our total sample) had no flags with either bioaerosols or bulk dust allergens (**Table 4-18**). Approximately an equal proportion (~ 19%) of homes had a flag with either bioaerosol or bulk dust allergens. The majority of homes in this analysis demonstrated flags with both types of allergens. **Figure 4-20** demonstrates the distribution of BA, BD, and BABD homes in the three regions. The Coastal Plain has the highest proportion of homes without flags (11.1%) as well as BD flags (31.5%). The Coast demonstrated the highest level of BA flags (23.4%), while the

Piedmont had the greatest level of BABD flags (69.8%). *Chi*-squared analyses found significant associations between the geographic region and BA flags ($\chi2 = 12.8$, $p=0.002$), as well as between region and BABD flags ($\chi2 = 8.0$, $p=0.02$).

**Table 4-18. Co-occurrence of bioaerosol and bulk dust problems in sample homes.**

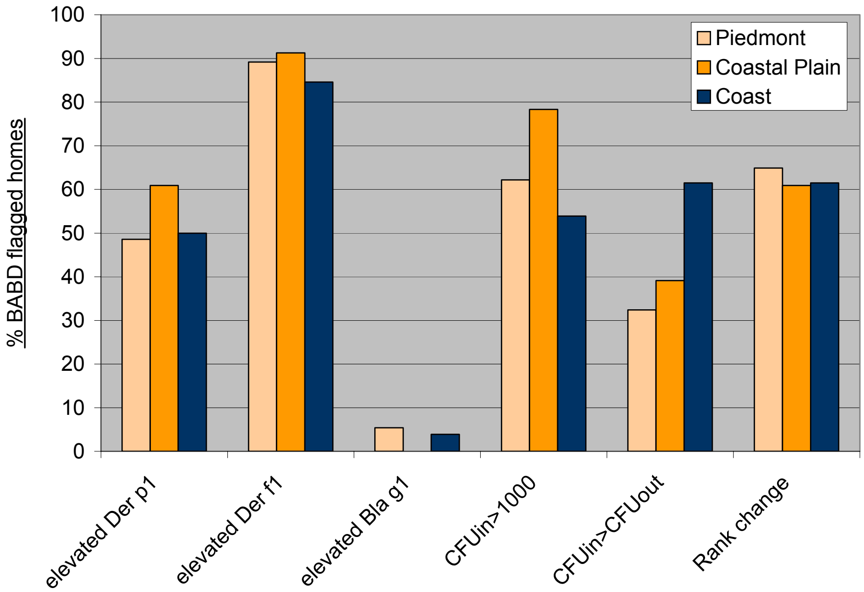
| | No bulk dust problem | Bulk dust problem |
|---|---|---|
| **No bioaerosol problem** | 10 (6.5%) | 30 (19.5%) |
| **Bioaerosol problem** | 28 (18%) | 86 (56%) |

**Figure 4-20. Distribution of bioaerosol (BA), bulk dust allergen (BD) and joint (BABD) flags across geographic regions.**




We next analyzed the underlying cause for the BABD flags across regions (**Figure 4-21**). The Der f1 allergen was the most common problem overall, with 88.4 % of homes exceeding levels for symptom exacerbation. In contrast, cockroach allergen was almost never a problem, particularly in the Coastal Plain, where no homes exceeded the level of concern. With respect to BA problems, the most common problem was that the indoor sample exceeded the airborne fungal count benchmark of 1000 CFU. This problem showed considerable variation across regions, affecting 53.9 % of the homes on the Coast, but affecting 78.3% of the homes on the Coastal Plain. A much higher percentage of homes with BABD flags on the Coast (61.5%) also showed a problem with indoor bioaerosol levels that exceeded outdoor levels compared to the Piedmont and Coastal Plain, where less than 40% of the homes experienced the same problem.

**Figure 4-21. Underlying causes for BABD flags across regions.**




Our logistic regression analysis revealed five variables that relate to homes with BABD flags (**Table 4-19**). Percent forest cover in the 500 m surrounding a home positively relates to the likelihood of a BABD flag, while the other four variables show negative relationships with BABD problems. Forest cover most likely contributes to elevated BA levels; however, it may also contribute to a microclimate that is more hospitable to dust mites and cockroaches. Ownership of either a cat or a dog decreases the likelihood of a joint problem, suggesting that pet ownership may result in home behavior that reduces the accumulation or growth of allergens in the home environment. Renters also appear to have a lower likelihood of a joint BABD problem. Lastly, the age of the home appears to influence the occurrence of a BABD flag; newer homes have a lower probability of a BABD flag. Comparing these results with above, we see that the higher proportion of forest cover surrounding homes in the Piedmont likely influences the higher proportion of BABD homes found there.

**Table 4-19. Logistic regression for co-occurrence of BA and BD flags.**

| Statistics | Equation |
|---|---|
| N=148<br>LR chi2(5) = 20.92<br>p = 0.001<br>Pseudo $r^2$ = 0.103 | **BABD flag (0,1)** ~ 4.20 (% In-forest) – 1.02 (cat) – 0.81(dog) – 1.91 (rent) – 0.02(year) + 39.50 |
| | **% In-forest:** log-transformed % forested land cover within 500 m radius<br>**cat:** dummy variable for cat ownership (1=yes)<br>**dog:** dummy variable for dog ownership (1=yes)<br>**rent:** dummy variable for renter occupied (1=yes)<br>**year:** year home was built |

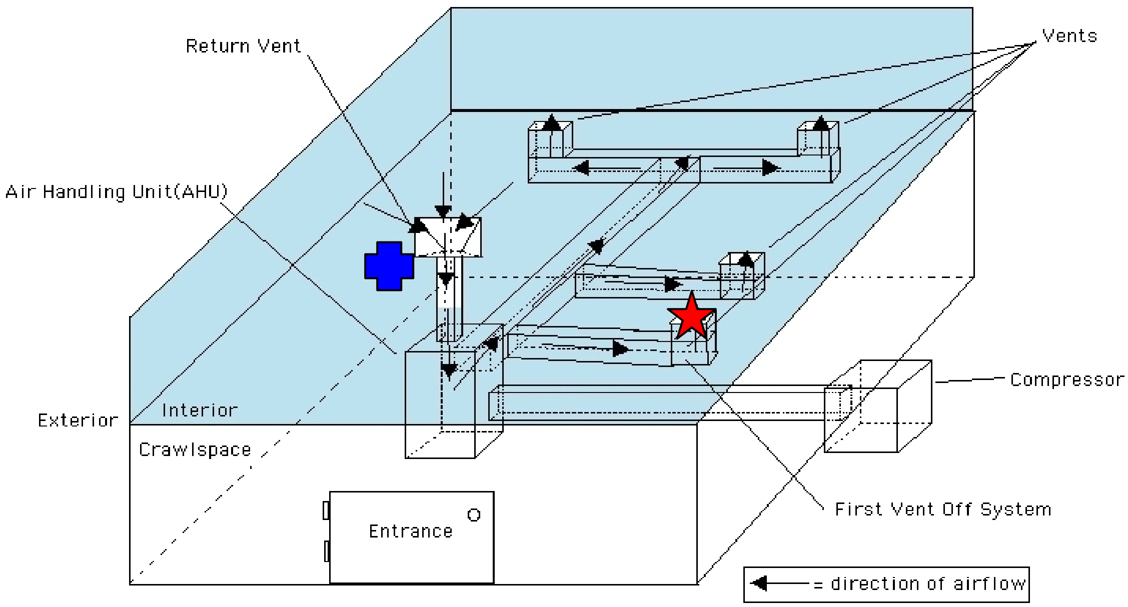
* denotes log-transformed variable

The joint analysis of bioaerosol and dustborne allergens shows that a majority of homes have problems with both air and dustborne allergens. Our analysis shows that homes located in forested areas appear to have a higher risk for problematic BABD levels. Resident in such areas should take precautions to reduce indoor allergen exposure and accumulation. Our results do not suggest any disproportionate impact for homes in low income or high minority areas.

## 4.6 Crawlspace characterization

In this study, we assessed mold contamination levels within crawlspaces and characterized whether air leakage from the heating, ventilation, and air conditioning (HVAC) system, and associated duct work, transports viable mold spores from the crawlspace into the living spaces within the home. The layout of a general crawlspace HVAC system is depicted in **Figure 4-22**, which demonstrates several features of the crawlspace environment that are important to this study. First, as was often the case in our participant homes, the ductwork for the HVAC runs through the crawlspace. This means that any small holes or gaps in the ductwork provide an opening through which fungal spores in the crawlspace air can be drawn into the HVAC system and transmitted into the interior of the home. Further, the red star in **Figure 4-22** corresponds to the first vent off of the HVAC system; air sampled in this location provides a direct measure of the contribution of HVAC air (and associated crawlspace impacts) to interior air quality. The blue plus sign in **Figure 4-22** represents the air near the return vent, which is a good composite measure of overall air quality in the home, combining air from a variety of sources, including HVAC air, leaks from crawlspace air, and leaks from outdoors.

**Figure 4-22. Simplified layout of a HVAC system in a crawlspace. Blue plus sign indicates location of indoor samples; red star indicates location of the diffuser samples (Diff1 and Diff2).**




### *4.6.1 Sampling Methodology*

Bioaerosol sampling preceded as described in **Section 4.1.1**. **Table 4-20** shows the locations in the home where we sampled for this study. Depending on housing characteristics, we sampled in either five locations (I1, O, CS2, I3, Diff2) or all eight locations (I1, O, CS1, I2, Diff1, CS2, I3, Diff2). Certain house characteristics rendered homes unsuitable to collect eight samples, and thus we only collected five samples in those homes. For all homes, we collected the samples in the order listed in **Table 4-20**. Crawlspace sampling occurred in three distinct stages. In stage one, we took three samples before the HVAC system fan was turned on: I1 near the "return" grill for the HVAC system (blue plus sign in **Figure 4-19**), O outside the house, and CS1 in the crawlspace using a non-invasive sampling technique. The non-invasive sampling technique used a tray attached to the end of a telescoping pole to hold the Anderson sampler (**Figure 4-23**). The pole was then inserted into the crawlspace without touching the ground or walls, and the sample was taken.

**Table 4-20. Bioaerosol sample codes.**

| Sample Order | Sample | Code | Location |
|---|---|---|---|
| 1 | Indoor One | I1 | Near the return vent for the HVAC system; HVAC off for 4+ hours. |
| 2 | Crawlspace One | CS1 | Non-invasive crawlspace sample, using sampler-on-a-stick; HVAC off for 4+ hours (**Figure** 4-1). |
| 3 | Outdoor | O | Outside, near most commonly used door, as identified by resident. |
| 4 | Indoor Two | I2 | Near the return vent for the HVAC system; HVAC on for >5 minutes. |
| 5 | Diffuser One | Diff1 | From the first diffuser that comes off the HVAC system; HVAC on for >5 minutes (**Figure** 4-2). |
| 6 | Crawlspace Two | CS2 | Invasive crawlspace sample, near the first drop off the HVAC system. |
| 7 | Indoor Three | I3 | Near the return vent for the HVAC system; >5 minutes after CS2 sample. |
| 8 | Diffuser Two | Diff2 | From the first diffuser that comes off the HVAC system; >5 minutes after CS2 sample |

**Figure 4-23: Non-invasive sampler used in study.**

In stage two, the HVAC system fan was turned on and allowed to run for at least 5 minutes. Then two additional samples were taken, I2 near the return grill again and Diff1 at a supply air diffuser (or register), designated by the red star in **Figure 4-22**. The supply diffuser sample was collected inside a short polyethylene tube that was temporarily taped around the supply register. The tube isolated the supply air from potential contaminant sources within the house, thus allowing characterization of the relative contribution of the HVAC system to the total fungal spore accumulation. In stage three, an invasive crawlspace sample, CS2, was taken close to the first drop from the air handling unit. This sample was taken by crawling into the crawlspace and holding the Anderson at least one foot off the ground to help contain inadvertent disruption once the vacuum was turned on. After the invasive crawlspace sample, the HVAC system fan was allowed to run for another five minutes after exiting the crawlspace. Two more interior samples were taken, I3 near the return grill and Diff2 at the same supply air diffuser. Samples were processed following the steps outlined in **Section 4.1.1**.

### *4.6.2 Transmission Classification.*

To assess the possibility of mold transmission from the crawlspace into the home, we classified homes into three categories: transmission (T), no transmission (NT), or indeterminate transmission (N/T~) homes. We developed the classification based on the levels, composition, and rank order of mold in the bioaerosol samples both before and after the HVAC system was turned on and both before and after the crawlspace was physically accessed. Transmission homes had an obvious link between the crawlspace and indoor bioaerosol levels, composition, and/or rank order. Non-transmission homes did not exhibit any link between the crawlspace and the indoor samples. Indeterminate transmission homes had some indicators of crawlspace transmission, but could not be distinguished from the possibility of mold growing in the home or HVAC system or the HVAC system pulling in outdoor air.

We sampled 238 homes for this study: 91 were 5-sample homes and 147 were 8-sample homes (**Table 4-21**). For the 5-sample homes, we classified eight as transmission homes, 50 as non-transmission homes, and 33 as indeterminate transmission homes. For the 8-sample homes, we classified 37 as transmission homes, 58 as non-transmission homes, and 52 as indeterminate transmission homes. **Figures 4-24** and **4-25** provide a summary of the total fungal levels in the five and eight sample homes, respectively. Crawlspace fungal levels exceeded 10,000 CFUs in all of the 8-sample homes.

**Figure 4-24. Median sample fungal counts for 5-sample homes.**

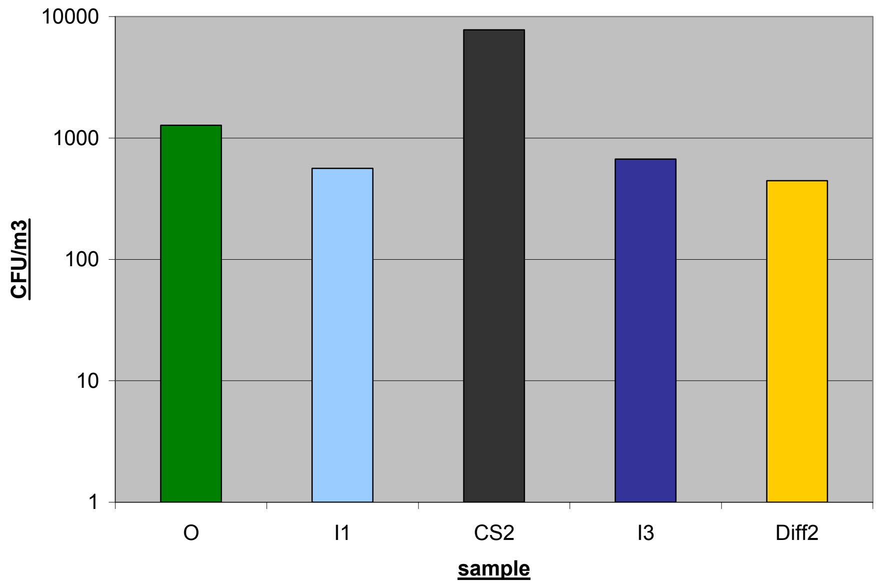


**Figure 4-25. Median sample fungal counts for 8-sample homes.**

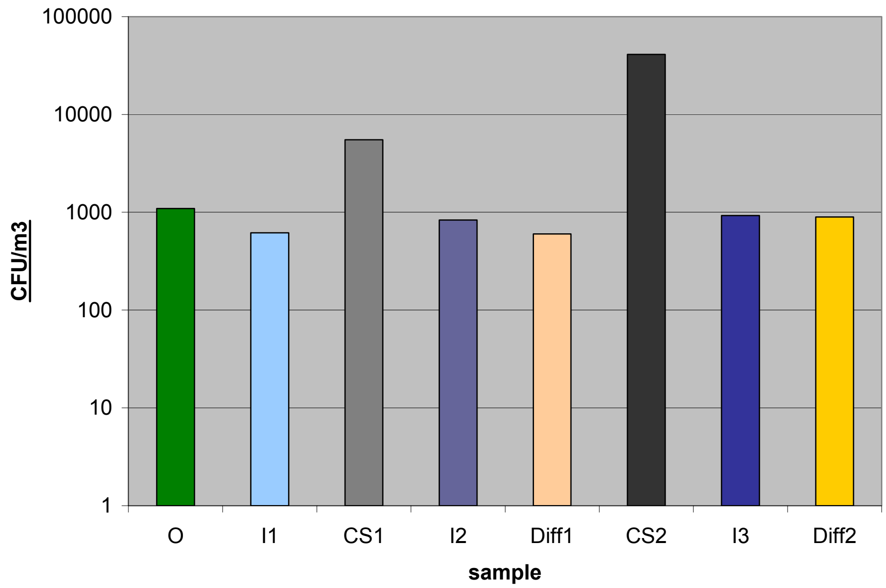



**Table 4-21. Distribution of homes across transmission categories for 5- and 8-sample homes.**

| | No Transmission (NT) Home | Transmission (T) | Indeterminate Transmission (NT/T~) |
|---|---|---|---|
| 5-sample | 50 (55%) | 8 (9%) | 33 (36%) |
| 8-sample | 58 (39%) | 37 (25%) | 52 (35%) |

### *4.6.3 Transmission Assessment*

**Statistical analysis.** Due to the small sample sizes, we analyzed potential transmission for 5-sample homes by comparing the two indoor fungal counts using a Wilcoxon matched-pairs signed rank test for each transmission grouping. Significant increases from the first to the second indoor fungal count are a major indication of fungal spore transmission from the crawlspace. We used t-tests for paired samples to test for differences across 8-sample home samples by transmission category. As the 8-sample homes have three indoor samples, we adjusted our alpha value to 0.017 for the indoor samples to reduce the likelihood of a Type I error. For the NT/T~ grouping, we split this group into two, those homes where *Penicillium* may be growing in the HVAC system and those where it likely is not. It is important to analyze the NT/T~ homes within this context as this condition represented a major reason why we could not distinguish between a T home and a NT/T~ home with mold growing in the HVAC system. For all statistical analyses we used Stata/SE for Windows version 9.0 (StataCorp LP, College Station, TX, USA) and an *alpha* value of 0.05.

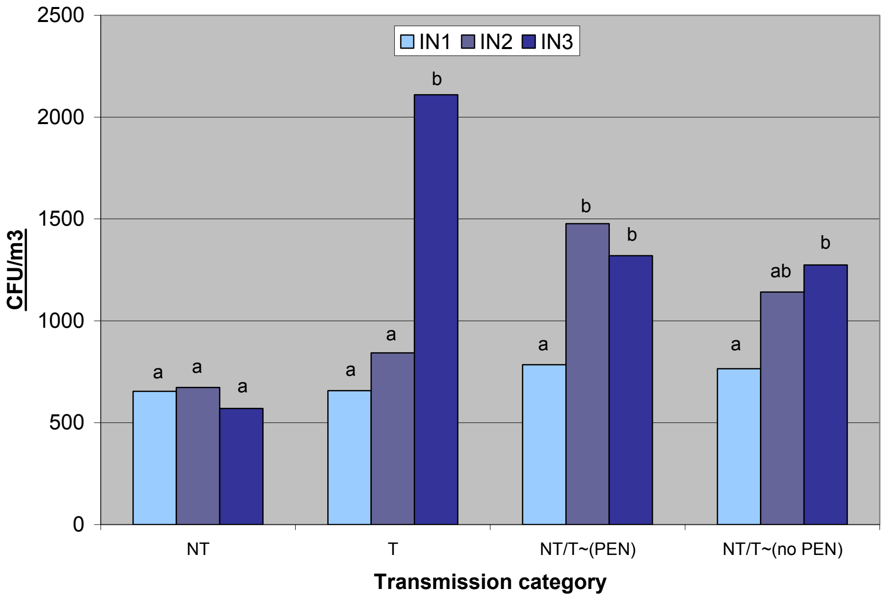
***Five-sample homes.*** Our analysis of the 5-sample homes support the classifications we determined above. Homes in the transmission likely category showed a significant increase in indoor total fungal counts after the crawlspace was disturbed by sampling (**Table 4-22**). The increase also caused the median home to exceed the benchmark value after crawlspace sampling (and likely any other similar disturbance). On the other hand, homes in the transmission not likely category showed no significant difference between the two indoor samples; in fact, the median values actually suggest a decrease from the first to the second sampling, indicating a filtering role for the HVAC system. For the transmission indeterminate homes, we observed a significant increase in homes where *Penicillium* may be growing in the HVAC system, but no significant increase in homes where this was not likely (the latter result is based on a low sample size; however, the trend in the samples is a decrease and thus does support the no significant increase finding. It is important to note that this category exhibited fungal counts considerably higher than the other categories).

**Table 4-22. Comparison of I1 and I3 for 5-sample homes using the Wilcoxon matched-pairs signed rank test.**

| Transmission Category | N | median I1 | median I3 | z-value | p-value |
|---|---|---|---|---|---|
| Likely | 8 | 367 | 1081 | -2.52 | 0.012 |
| Not Likely | 50 | 517 | 466 | 0.654 | 0.513 |
| Indeterminate—with Pen | 28 | 657 | 940 | -3.45 | 0.001 |
| Indeterminate—without Pen | 5 | 2158 | 1962 | -0.816 | 0.414 |

***Eight-sample homes.*** The analysis of indoor fungal counts for the 8-sample homes provided further confirmation of the transmission classifications. Homes classified with unlikely transmission showed no significant differences across the fungal counts in the indoor samples. In contrast, transmission likely homes showed a dramatic and statistically significant increase between the non-invasive (I2) and invasive (I3) crawlspace sampling, providing strong evidence that any resuspension of fungal spores in the crawlspace is rapidly transmitted into the home interior. The results from the indeterminate analyses also suggest some interesting relationships. In cases where *Penicillium* may be growing in the HVAC system, I2 and I3 levels were similar but both were significantly larger than I1. This suggests that the source of the increase lies in the HVAC system and not in the crawlspace, as the increase is more associated with the HVAC being turned on (and the resulting pressure differential) and not the crawlspace disturbance. For indeterminate homes where *Penicillium* is not likely growing in the HVAC system, there was no significant difference between I1 and I2 (**Figure 4-26**).

**Figure 4-26. Mean indoor sample fungal counts by transmission category. (columns with different letters represent significant differences across samples, p<0.017).**




The fungal counts in the crawlspace samples each exhibited substantial and statistically significant increases after the invasive sampling took place (**Figure 4-27**). The lower fungal levels in the CS2 samples of the NT homes suggest that part of the reason for decreased likelihood in these homes may relate to a lower level of fungal growth in the crawlspaces. This may result from different construction types, local environmental factors, or age of housing. Both indeterminate groupings appear to be intermediates between the transmission likely and not likely homes. Indeterminate homes with *Penicillium* possibly growing in the HVAC system also appear to have slightly higher levels of fungal growth in the crawlspace than the ones where this is unlikely. Another important feature of the crawlspace fungal levels is that their magnitude is substantially greater than that generally observed in the indoor and diffuser samples, indicating that the physical structure of the crawlspaces may be helping to elevate concentrations of mold spores. For the diffuser samples, only the transmission likely homes demonstrate a significant increase in fungal levels after crawlspace disturbance (**Figure 4-28**).

**Figure 4-27. Comparison of mean fungal counts in crawlspace samples by transmission category (columns with different letters represent significant differences across samples, p<0.05).**

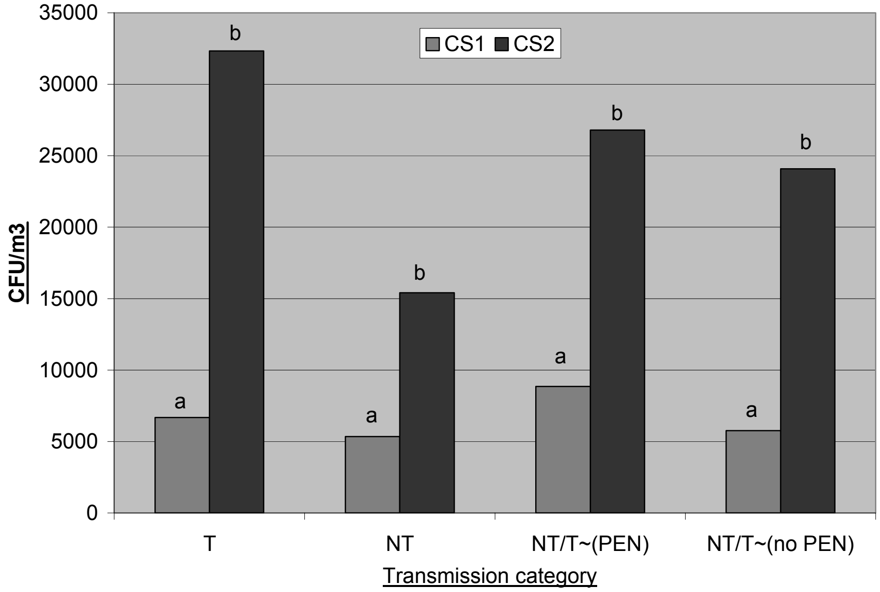
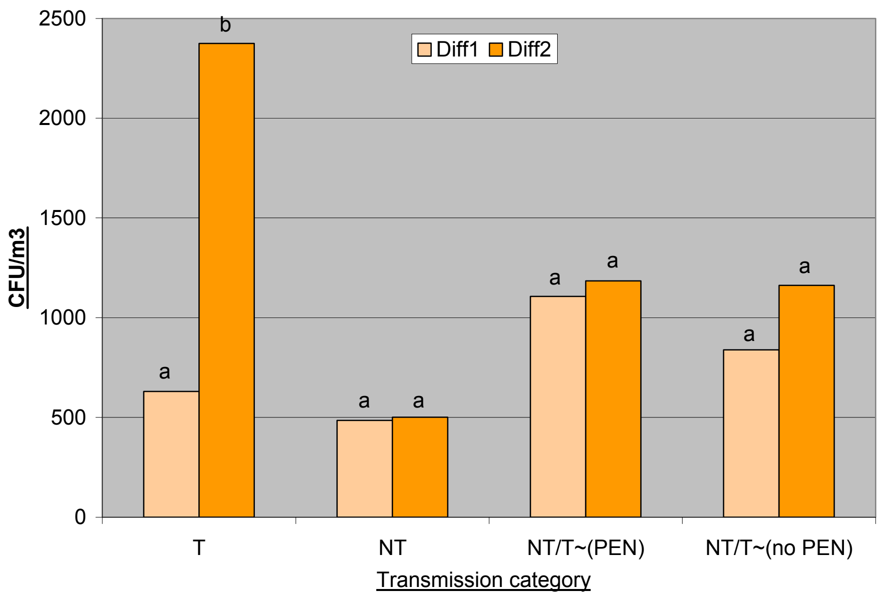



**Figure 4-28. Comparison of mean fungal counts in diffuser samples by transmission category (columns with different letters represent significant differences across samples, p<0.05).**



## 4.7 Analysis of Non-invasive and Invasive Crawlspace Sampling

In this section of the study, we investigate the impact of using a non-invasive sampling technique to measure airborne fungal spores in the crawlspace environment. This study has two important implications: 1) it reveals the effect that sampling method can have on indoor air quality; and 2) it reflects the impact other disturbances in the crawlspace (e.g. wind events, animal movement, or use of crawlspace for storage) can have on indoor air quality and exposure to allergens and asthma triggers.

### *4.7.1 Methods*

We followed the sampling methodology laid out in **Sections 4.1.1** and **4.6** for 8-sample homes. We analyzed differences across sampling methods (non-invasive and invasive) for total fungal count and the proportions of each fungal grouping using a Wilcoxon matched-pairs signed rank test (STATA 9.0). We set our *alpha* level to 0.05.

### *4.7.2 Fungal Counts Findings*

We found that invasive crawlspace sampling (sampling technician physically crawled into crawlspace to take sample) significantly increased the level of airborne fungal spores (**Figure 4-29**), the geometric mean increased from 6455 CFU/$m^3$ for the non-invasive method to 23222 CFU/$m^3$ for the invasive sampling. This increase is reflected in both the indoor and diffuser samples taken for the home (**Figure 4-30**), suggesting crawlspace air is pulled into the home through the HVAC system and other leaks.

**Figure 4-29. Geometric mean of total airborne fungal levels in crawlspace by sampling method.**

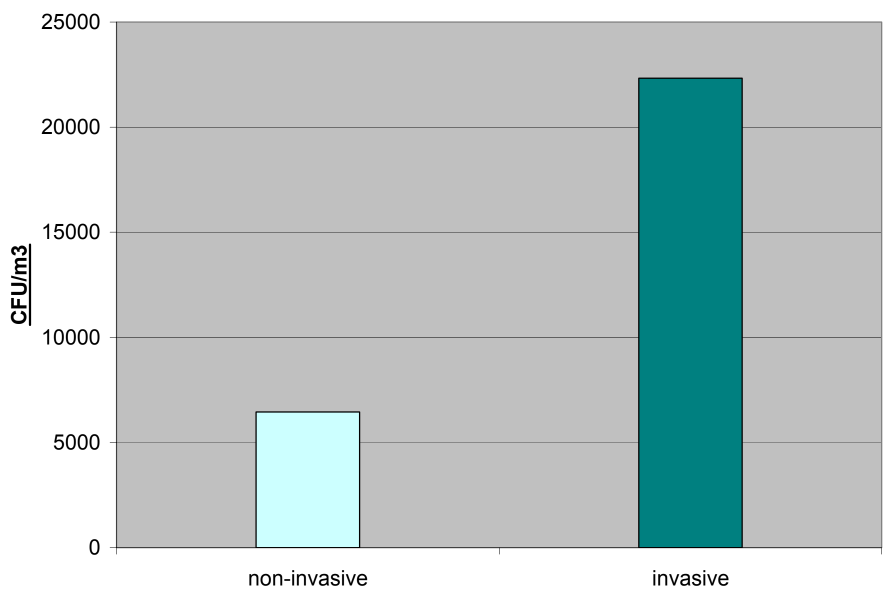
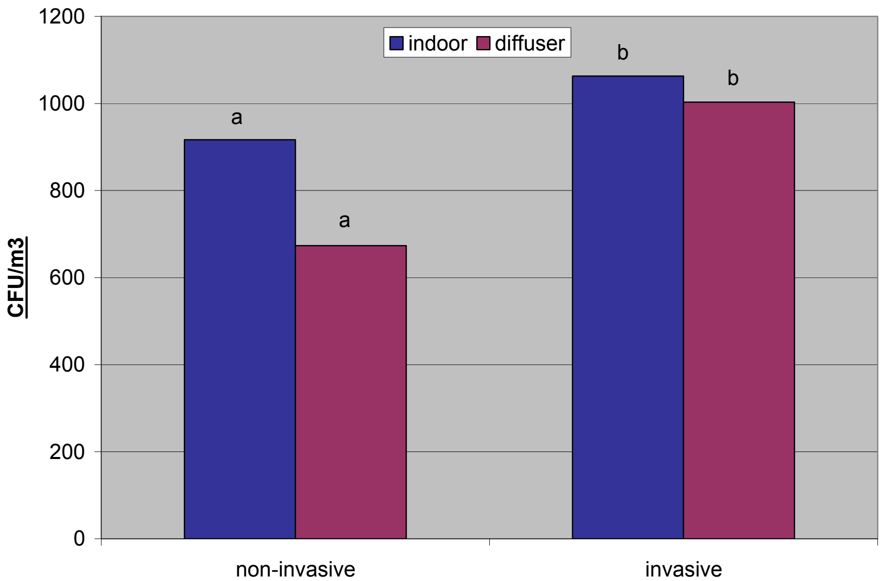


**Figure 4-30. Geometric mean of total airborne fungal levels in indoor and diffuser samples, by sampling method. (Columns possessing different letters indicate significant differences across sampling method, p< 0.05).**




*4.7.3 Fungal Sample Composition*

Every group in the crawlspace showed significant changes after invasive sampling (**Figure 4-31**). The proportion of *Cladosporium* (Z=6.850, p=0.000), *Mycelia sterilia* (7.446, p=0.000), and *Other* (Z=3.382, p=0.001) all showed significant decreases after invasive sampling. Conversely, the proportion of *Penicillium* (Z= -3.116, p=0.002) and *Aspergillus* (Z= -3.080, p=0.002) both showed significant increases. The median values for both *Aspergillus* (range: 0 – 0.681) and *Other* (range: 0 – 0.287) were zero for all samples. These findings demonstrate the impact that activity in the crawlspace can have on fungal levels. In particular, such activity appears to stir up *Penicillium* and *Aspergillus* spores that had settled out onto the crawlspace floor. As both of these genera are known respiratory irritants, this finding highlights the necessity of limiting disturbances in the crawlspace.

The diffuser samples provide an insight into how crawlspace air might be transmitted into the inhabited portion of a home via the HVAC system. Diffuser samples also showed significant shifts in fungal composition after invasive sampling (**Figure 4-32**). The proportion of *Cladosporium* decreased (Z=4.121, p=0.000). The same held true for *Mycelia sterilia*, although the decrease was only borderline significant (Z=1.775, p=0.076). The proportion of *Penicillium, Aspergillus* and *Other* showed no significant difference after invasive sampling. The median values for *Aspergillus* (range: 0 – 0.423) and *Other* (range: 0 – 0.282) were zero for each sample

**Figure 4-31. Median fungal group proportions in crawlspace samples by sampling method (Columns possessing different letters indicate significant differences across sampling method, p< 0.05).**

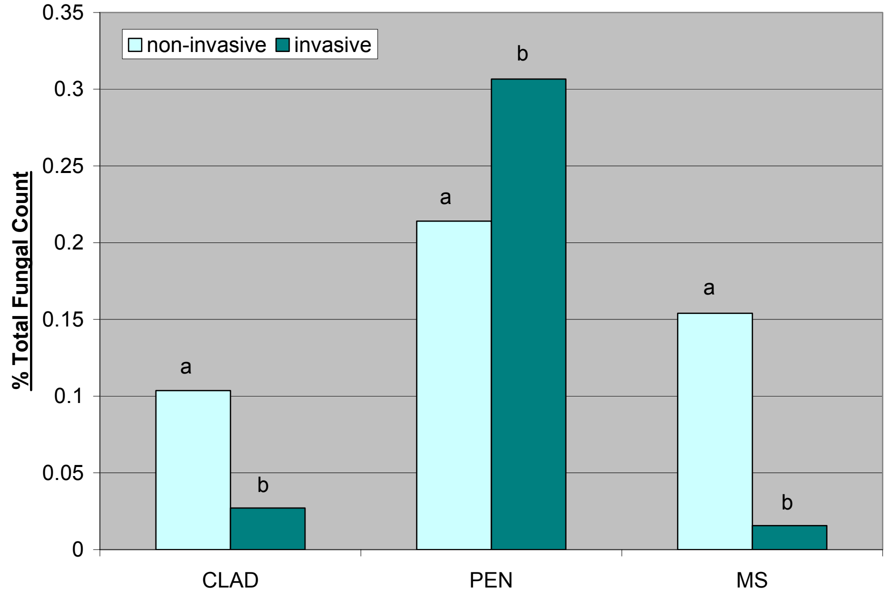
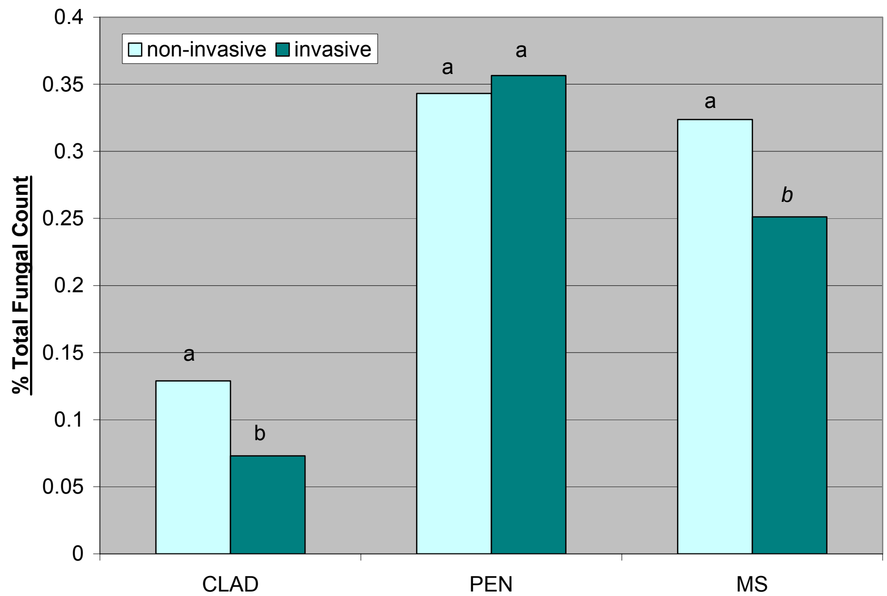


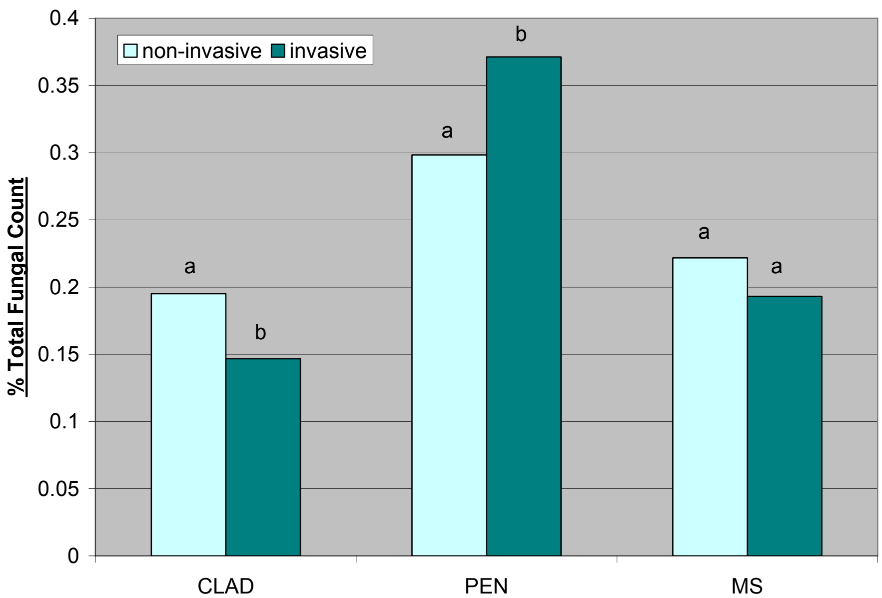

**Figure 4-32. Median fungal group proportions in diffuser samples by sampling method (Columns possessing different letters indicate significant differences across sampling method, p< 0.05. NB: the p-value for MS was 0.076).**




An analysis of fungal community proportions in the indoor samples showed several significant changes after invasive sampling (**Figure 4-33**). The proportion of *Cladosporium* decreased (Z=4.563, p=0.000), while the proportion of *Penicillium* increased (Z=-3.249, p=0.001). *Mycelia* *sterilia* levels showed no significant difference across sampling pre- and post-crawlspace access. The median values for *Aspergillus* in the indoor samples were zero both pre- and post-crawlspace access (range: 0 – 0.643). Nonetheless, the results of the Wilcoxon matched-pairs signed rank test (Z= -3.189, p=0.0014) suggest that *Aspergillus* levels generally increased after invasive crawlspace sampling. The analysis of *Other* grouping, which also had median values of zero for each sample (range: 0 – 0.225), showed no difference across sampling time.

The indoor samples provide a composite view of transmission from the crawlspace into the inhabited portion of the home by encompassing both HVAC contributions (which are seen in the diffuser samples) and contributions through leaks from the crawlspace into the house interior. Comparing these results with the diffuser samples, our results indicate that the most likely transmission route may vary by types of mold.

**Figure 4-33. Median fungal group proportions in indoor samples by sampling method. (Columns possessing different letters indicate significant differences across sampling method, p< 0.05).**




Overall, this portion of the project highlights the important role crawlspace construction plays with respect to respirable bioaerosols in the home environment. Human, animal, and weather-related disturbances of the crawlspace may stir up fungal spores, thus facilitating their transmission into the home environment. Our results point to the importance of sealing leakages between the crawlspace and the home interior to avoid potential transmission of serious allergen and asthma triggers. Nonetheless, transmission via the HVAC system remains possible. Homes with asthma or allergy sufferers should take necessary precautions to limit disturbance of crawlspaces and subsequent transmission of bioaerosol indoors.

## 4.8 Advanced Energy's Phase II

### *4.8.1 Crawlspace Characterization*

Duke contracted with Advanced Energy to conduct a building science evaluation to characterize the conditions of typical wall vented crawlspaces in 40-50 homes in Durham, New Hanover, Wayne, and Wilson Counties, a subset of the homes studied by Duke.

Indoor air quality researchers have increasingly focused on mold as a household pollutant. Because crawlspaces experience periodic high levels of moisture, they are very likely areas where mold may be found. Advanced Energy conducted a building science characterization on 46 houses to determine whether the presence of crawlspace mold results in mold exposure to occupants in the home. The characterization protocol recorded a wide variety of data, including a homeowner interview, temperature readings, relative humidity readings, building pressure diagnostics, documentation of topographical and exterior water transport issues, visual inspections of crawlspace moisture history, wood moisture meter readings, information about the house foundation and crawlspace construction, and insulation quality. Duke University conducted the bioaerosol sampling for this study, using the methods described above.

*Homeowner Interview*

Thirty-eight percent of the study sampling was conducted during the humid season (May through September) and 62 percent in October through December, considered the non-humid season. Twenty-two homes were sampled in New Hanover, 11 in Durham, 10 in Wilson, and 2 in Wayne Counties. House ages ranged from 2 to 60 years, with 27 years being the mean. Average length of occupancy was 16 years, ranging from 1 to 60 years.

The crawlspace was frequently used for storage of gas, paint, and other materials. Fifty-six percent of households used crawlspaces for storage and 44 percent for plumbing repair or maintenance of the HVAC components, water heater, or other equipment. Seventy-seven percent of homeowners did not operate their crawlspace vents. Fifty-three percent of homes reported having a family member with allergies, 29 percent with asthma, and 11 percent having both asthma and allergies. The average thermostat settings were 70ºF and 75ºF during the heating and cooling seasons, respectively. The majority of people changed their thermostats at night (56%) and used the automatic mechanism to operate their HVAC fan (86%).

*Home Description*

The majority of houses in the study were one-story homes (51%), followed by two-story homes (44%) and one and a half story homes (4%). Twenty-five had brick exteriors, 14 had siding, and 5 had a combination of brick and siding.

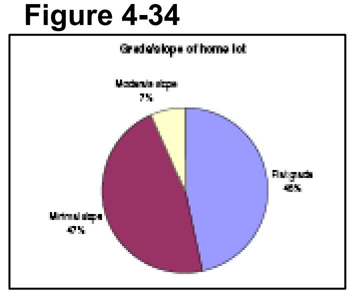
*HVAC System*

Fifty-five percent of HVAC units were heat pumps, 34% gas packs, 7% furnace-air conditioning packs, and 5% other. All but one house had the supply and return ducts in the crawlspace. Thirty-three percent of the houses had the air handler in the crawlspace. Of these, three had condensate drains going uphill and leaking. Two homes had a humidifier attached to the duct system in the crawlspace, and two had a dehumidifier in the conditioned space.

*Topographical and Water Transport Assessment*

Of the lots with minimal or moderate grades, 10 were sloped away from the house and 23 had slopes higher on one side of the house than the other. **Figure 4-34** summarizes the grade/slope of the lot. Seventy-seven percent of the houses had both gutters and downspouts. Of the homes with gutters, 30% were observed to have gutter clogging

**Figure 4-34**



or spillover at the time of the visit. Only 26% of the houses possessed sprinkler systems next to the house foundation. Ninety-six percent of the houses had spigots fastened to the house foundation wall, and saturated soil was visible next to the foundation in 31 percent of the houses. Most houses (84%) had plants next to the foundation.

*Temperature and Relative Humidity*

**Table 4-23** represents the temperature, relative humidity, and dew point data for one measurement taken at the time of the visit. For houses sampled in July and August, the outside dew point temperature was higher than the crawlspace dew point temperature. In September, half of the houses sampled had higher outside dew points than crawlspace dew points. Temperature data was also collected in the crawlspace for the ground, water pipes, and duct work. **Table 4-24** displays the mean temperature for each area.

**Table 4-23: Ambient conditions**

| | | Crawl space | | | Outdoor | | |
|---|---|---|---|---|---|---|---|
| | # | Temperature (°F) | Relative humidity (%) | Dew point | Temperature (°F) | Relative humidity (%) | Dew point |
| July | 4 | 74 | 82 | 68 | 82 | 75 | 73 |
| August | 3 | 73 | 83 | 68 | 77 | 80 | 70 |
| September | 10 | 81 | 63 | 67 | 76 | 71 | 66 |
| October | 11 | 71 | 68 | 60 | 64 | 73 | 55 |
| November | 12 | 65 | 59 | 50 | 60 | 58 | 45 |
| December | 5 | 67 | 60 | 53 | 59 | 64 | 47 |

**Table 4-24: Mean temperatures**

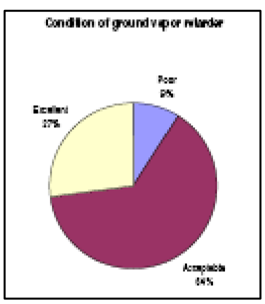
| | Study temperature (°F) | | |
|---|---|---|---|
| | Ground | Water pipes | Duct work |
| Mean | 68 | 71 | 70 |
| High | 76 | 90 | 81 |
| Low | 61 | 61 | 62 |

*Crawlspace Moisture*

Two houses were found to have wet crawlspace ground at the time of the visit, two were borderline damp to wet, nine were damp or moist, and 19 were dry. Of 19 homes with data about water pipe moisture, one had wet pipes, three were damp, and 15 were dry. Of the 20 houses with information on duct work moisture, three were wet, nine were damp, and nine were dry.

*Crawlspace Construction and Condition*

**Figure 4-35**




Seventy-three percent of crawlspaces had a ground vapor retarder, either 6 mil poly or 4 mil poly. However, all of the vapor retarders lacked full coverage, and 84% had less than 90% coverage. **Figure 4-35** classifies ground vapor retarder condition as either poor, acceptable, or excellent. Of the 33 crawlspaces with vapor retarders, 14 had puddles on the ground vapor retarder. Of the 28 houses for which sump pump information was obtained, 22 homes did not have a pump. All homes with information lacked a sill gasket. Of the 27 homes for which water proofing data was available, 25 crawlspaces did not have water proofing on the exterior. Of the 43 houses for which crawlspace drain information was obtained, 53% did not have a crawlspace drain.

Twenty-two percent of the houses had drip lines on the soil in the crawlspace at the time of sampling. Forty-nine percent of crawlspaces had visible discoloration, and of these 22 homes, 9 nine had discoloration on three or more crawlspace walls. Forty-four percent of the crawlspaces also had signs of efflorescent salts leaching through the walls. Thirty-three percent of the houses showed condensation on duct or pipe surfaces, 16% of houses had waterlogged ducts, and 31% had plumbing leaks.

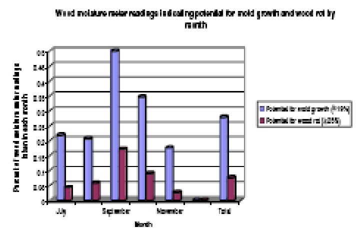
The majority of homes (62%) had visible mold in the crawlspace. Of the 28 houses with visible mold, 10 had minimal mold, seven had some, two had significant amounts, and nine were not classified. Forty-seven percent of crawlspaces had internal wood rot and 22% had external wood rot.

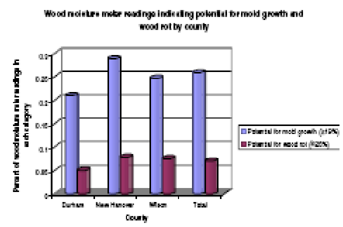
*Moisture Readings*
Nineteen percent of homes had wood moisture readings at the mold-supporting level and 25% had readings at the wood rot-supporting level. **Table 4-24** shows the results of wood moisture readings for all houses. **Figures 4-36** and **4-37** display wood moisture meter readings indicating mold growth and wood rot by county and month, respectively.

**Table 4-24: Wood moisture readings.**

| | # readings for all houses | | | % of readings | |
|---|---|---|---|---|---|
| Location | Potential for mold growth (• 19%) | Potential for wood rot (• 25%) | Total | Potential for mold growth (• 19%) | Potential for wood rot (• 25%) |
| Sill (access) | 6 | 0 | 37 | 16% | 0% |
| Joist (access) | 5 | 0 | 45 | 11% | 0% |
| Joist (access, below insulation) | 11 | 0 | 45 | 24% | 0% |
| Joist (access, above insulation)* | 3 | 0 | 36 | 8% | 0% |
| Center joist (below insulation) | 17 | 4 | 43 | 40% | 9% |
| Center joist (above insulation)* | 4 | 2 | 34 | 12% | 6% |
| Sill (worst) | 11 | 1 | 34 | 32% | 3% |
| Joist (worst) | 13 | 4 | 43 | 30% | 9% |
| Joist (worst, below insulation) | 20 | 7 | 43 | 47% | 16% |
| Joist (worst, above insulation)* | 10 | 3 | 35 | 29% | 9% |
| Sub floor | 13 | 7 | 43 | 30% | 16% |
| Other worst | 17 | 8 | 29 | 59% | 28% |
| Total | 130 | 36 | 467 | 28% | 8% |

**Figures 4-36 and 4-37**




*Air Leakage*
Eighty percent of the crawlspaces have insulation under the subfloor in the crawlspace, and all of them used tension wires as the mounting technique. Of the crawlspaces with insulation, 26% of insulation was wet, 60% had visible unplanned holes, 23% had significant compression due to tension wires, 60% had some fallen insulation, 71% had some hanging bats, 54% had some delaminated bats, 74% had compromised insulation at band joist, 26% had compromised insulation at floor penetration, and 11% had insulation with significant bypass.

Monitoring air leakage between various parts of the home helps determine the potential for transport of air and airborne contaminants. Three leakage paths were measured: total house air leakage, air leakage between the living space and the crawlspace, and air leakage between the duct work and crawlspace. Using classifications based on cubic feet per minute at 50 Pascals (CFM 50) per square foot of surface area, 13% had major leakage, 20% had excessive leakage, 42% had moderate leakage, 24% had limited leakage, and zero had minimal leakage.

Crawlspace to house air leakage quantifies the amount of air exchange resulting from holes in the floor between the crawlspace and the house. The majority of homes (69%) had between 11% and 30% of the total house air leakage coming from the crawlspace.

Air leakage in crawlspace ducts represents the amount of air in CFM passing through holes or gaps in the ductwork. Using classifications based on cubic feet per minute at 25 Pascals (CFM 25) per square foot of floor area, 65% had major duct leakage, 18% had excessive leakage, 9% had moderate leakage, 4% had limited leakage, and zero had minimal leakage. Five homes were not classified because they were unable to reach their target pressure.

This study documented that typical wall vented crawlspaces possess the following characteristics:

- *Presence of liquid water, moisture vapor and associated moisture issues.*

In humid months, wet outdoor air enters the crawlspace and condenses on surfaces with temperatures at or below the dew point. Crawlspaces also had evidence of liquid water intrusion, leading to visible wood rot, visible mold, efflorescent salts leaching through walls, and discoloration.

- *Contaminants that may be harmful to human health.*
  Bioaerosol results showed higher levels of colony forming units in the crawlspace than other locations sampled. In addition, many used the crawlspace for storage of toxic chemicals that could be transmitted into the living space.
- *Measured holes between the crawlspace and living space.*
  The majority of houses (31 of 45) had somewhere between 11% and 30% of total house air leakage coming from holes in the floor between the crawlspace and the house.
- *Forces (natural and mechanical) that drive crawlspace air across the holes.*
  Through a stack effect, warm air in the house rises and exits through holes in the ceiling and upper walls, drawing cool air up through holes in the floor and lower walls. Duct systems were also leaky, introducing crawlspace air into the living space. Return duct leaks pull airborne pollutants, spores and water vapor into the duct work and redistribute these indoor air quality hazards into the livable parts of the house by use of the HVAC system.

### *4.8.2 Temperature and Relative Humidity Study*

Through Duke's contract with Advanced Energy to evaluate crawlspaces as a source of mold in the livable part of the home environment, Advanced Energy conducted a long term study of temperature and relative humidity in addition to the crawlspace characterization study in the subset of 46 homes.

During the initial crawlspace characterization sampling visit, researchers installed a Hobo Pro data logger in the crawlspace of each study home to measure and record hourly temperature and relative humidity, and then calculate dew point temperature. In the high resolution mode used for this study, temperature accuracy was ± 0.33ºF at 70ºF and RH accuracy was ± 3% from 32ºF to 122ºF and ± 4% in condensing environments. Researchers installed data loggers near the crawlspace access and recorded conditions for approximately three months to one year. The first data logger was installed on July 22, 2004 and the final logger on December 8, 2004. Five loggers experienced malfunctions and all data loggers were stopped as of September 5, 2005. Due to the staggered launch dates, data analysis is based on data recorded between the dates of October 15, 2004 and September 5, 2005. This data was used to document the long-term moisture performance of wall-vented crawlspaces, focusing on the humid summer months of June, July and August, 2005.

*Outside and Crawlspace Temperatures*
Outside conditions including temperature, relative humidity, and dew point were similar across counties. Crawlspace temperatures were similar for all counties. In the summer months, New Hanover, Wayne, and Wilson Counties ranged from approximately 70ºF to 75ºF, while Durham County was slightly cooler, ranging from 68ºF to 73ºF. During winter, fall, and spring months, the outdoor temperature generally remained below the crawlspace temperature for all counties, while the outdoor temperature remained above the crawlspace temperature during the summer months. Crawlspace temperatures were less variable than outside temperatures.

*Crawlspace Relative Humidity*
One hundred percent of crawlspace readings in June and July and 99% of readings in August were at or above 70% RH and the majority were above 90% RH. Seventy percent RH is the commonly accepted threshold above which mold growth is supported. Comparing average

crawlspace humidity across all counties showed that during summer months, crawlspaces in all counties remained above levels supporting mold growth. **Figure 4-39** shows that all average summer RH levels exceeded 80% and most Wayne, Wilson, and New Hanover readings exceeded 90%. When looking only at the summer months, the crawlspace RH was, on average, higher than the outside RH. **Figure 4-40** shows this trend for Durham County.

**Figure 4-39**

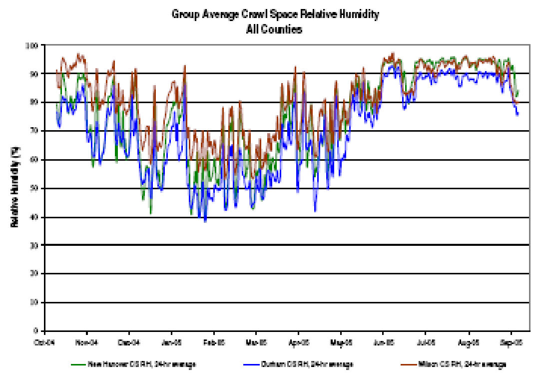
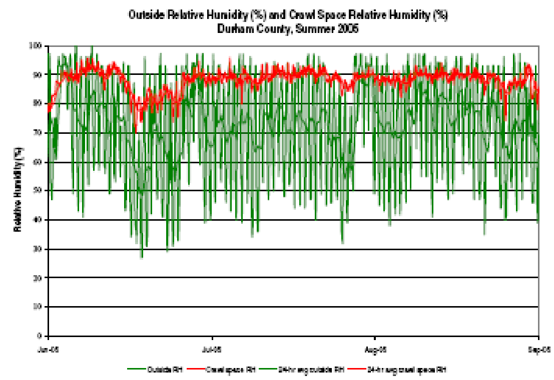



**Figure 4-40**




*Crawlspace Dew Point*

Dew point results show that Wayne, Wilson, and New Hanover Counties had higher average dew point temperatures than Durham County, indicating that they were wetter. During the summer months, for all counties, the outside dew point temperature was higher than the crawlspace dew point temperature, indicating that outside air was wetter than crawlspace air (See **Figure 4-41** and **4-42** for New Hanover).

**Figure 4-41**

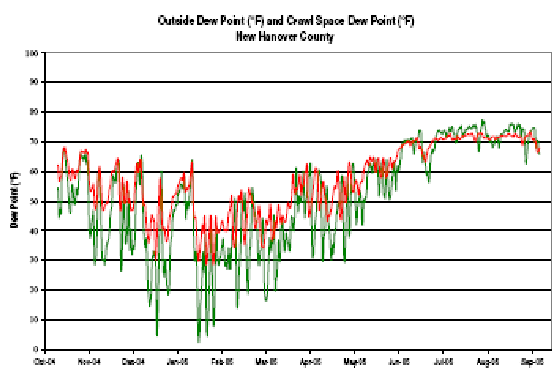
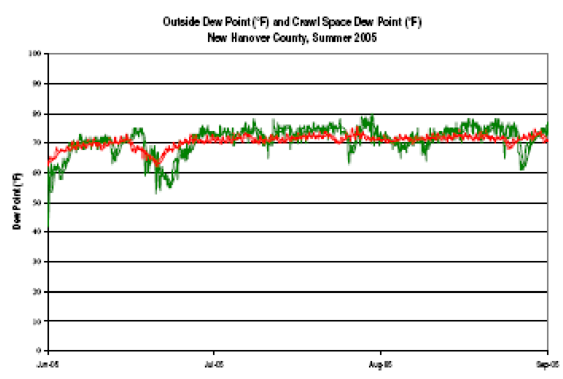



**Figure 4-42**



The outside and crawlspace dew points show that the summer outside air was wetter than crawlspace air, offering no potential for drying. Comparing the outside dew point and the crawlspace temperature determines the possibility of condensation. During the summer months, the outside dew point exceeded the crawlspace temperature on numerous occasions. If the outside air enters the crawlspace and contacts surfaces that have a temperature lower than its dew point, the water vapor in the outside air will condense on that surface. **Figure 4-43** focuses on Durham County in the summer months, displaying that during much of the summer, condensation is possible in these crawlspaces. The same trends were found in the other studied counties.

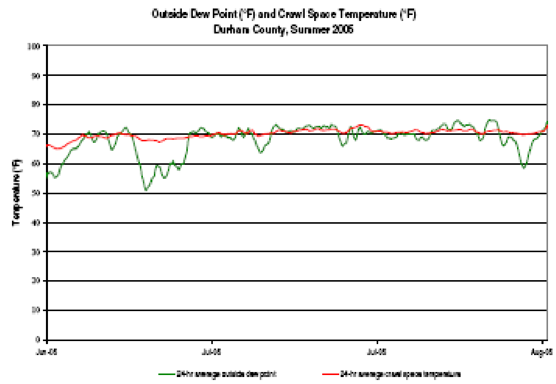



**Figure 4-43**

*Effects of Crawlspace Dehumidifiers on RH*

A few homeowners used dehumidifiers in their crawlspaces to control humidity levels. Results indicated that operating a dehumidifier is one way to reduce RH levels, but does not guarantee that RH levels will be reduced enough to impede mold growth.

Results showed that venting crawlspaces with outside air does not dry the crawlspace nor does it have the potential to dry the crawlspace during the summer months. Summer outdoor air was confirmed to be wetter than crawlspace air and outdoor dew point temperatures frequently exceeded crawlspace temperatures, potentially resulting in condensation. Not only did the liquid water from condensation create conditions that support mold growth but relative humidity levels alone were found to be at levels sufficient to support mold growth. Nearly 100% of crawlspace relative humidity readings exceeded the threshold for mold growth during the summer seasons of June, July and August, 2005.

## 4.9 Evaluation of Fire Risks

This part of the study was designed to evaluate the risk of fire in the home environment in NC, which we assessed by evaluating the presence and functioning of smoke detectors in participant homes. This analysis derives from 685 homes sampled from 2001 to 2004.

### *4.9.1 Presence of Smoke Detectors*

The vast majority (> 95%) of the homes in this project possessed at least one smoke detector (**Figure 4-44**). In the Coastal Plain and on the Coast, approximately equal percentages of homes had either one or two smoke detectors (~ 40% each). In contrast, over 50% of Piedmont homes had two smoke detectors, while the percentage of homes with just one detector was less than 30%. The main predictor for the presence of a smoke detector in a home was household median income (**Table 4-25**): the higher the income the greater the likelihood of having a detector. Homes in areas with higher percentages of African-Americans or in urban locations also appear more likely to have smoke detectors, although both relationships bordered on statistical significance.

**Figure 4-44: Number of smoke detectors per home by region**

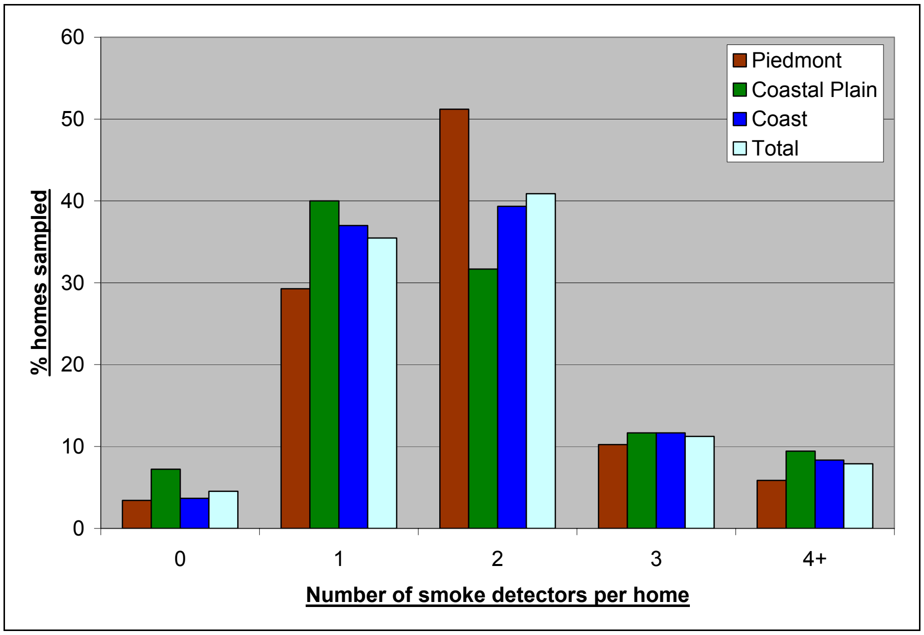



**Table 4-25: Factors associated with having smoke detectors. [n=654; LR *chi*$^2$ (4) = 19.47, p=0.0006, pseudo $r^2$ = 0.080]**

| Variable | In transform? | odds ratio | p-value |
|---|---|---|---|
| % African-American (block) | yes | 1.28 | 0.078 |
| Household median income (blockgroup) | yes | 4.23 | 0.002 |
| Urban location (dummy variable) | NA | 2.47 | 0.086 |
| Total parcel value | yes | | |

### *4.9.2 Smoke Detector Functioning*

An analysis of our data indicates that the majority of smoke detectors in our study functioned (i.e. they sounded when activated). Homes on the Coast had the highest level of functioning smoke detectors, while homes in the Coastal Plain had the lowest level (**Figure 4-45**). At least 23% of homes in all regions and as many as 31% of homes in the Coastal Plain had non-functioning smoke detectors. Homes where we conducted the interview in Spanish were much more likely to not have functioning smoke detectors (**Table 4-26**), while newer homes were slightly more likely to have functioning smoke detectors. Homes in areas with higher percentages of renter-occupied housing also appear to have a greater probability of non-functioning smoke detectors, although the relationship was outside the bounds of statistical significance (p=0.126). The finding about the Spanish-language participants is particularly worrisome, as many of these families were poor, immigrant families with few resources and minimal English language ability.

**Figure 4-45: Mean percentage of functioning smoke detectors in homes with smoke detectors, by region.**

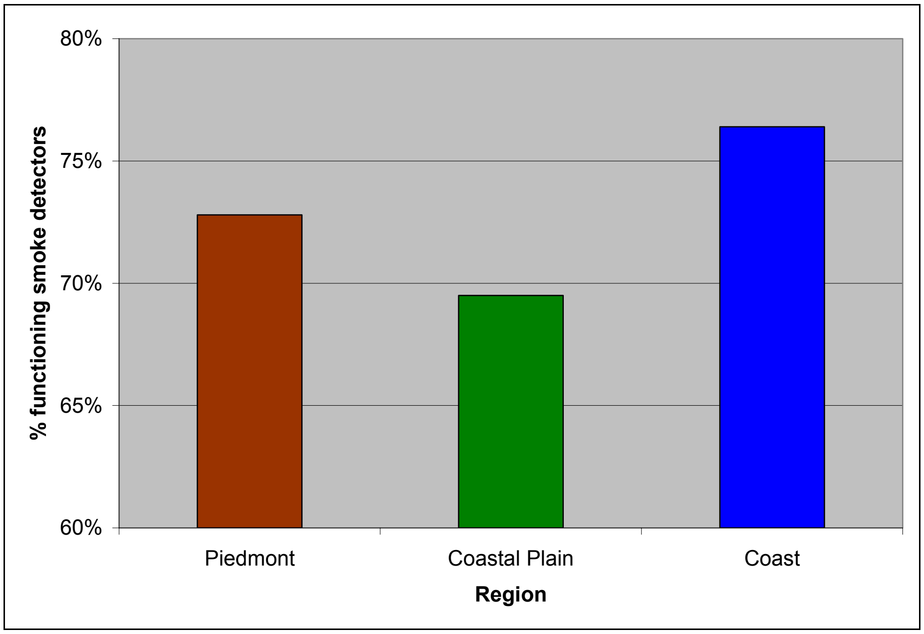



**Table 4-26: Factors associated with having functioning smoke detectors. [n=644; LR *chi*$^2$ (3) = 30.53, p=0.0000, pseudo $r^2$ = 0.047]**

| Variable | In transform? | odds ratio | p-value |
|---|---|---|---|
| Spanish language household (dummy variable) | NA | 0.373 | 0.008 |
| Median year built (blockgroup) | no | 1.025 | 0.000 |
| % renter-occupied housing (block) | yes | 0.880 | 0.126 |

# 5.0 CONCLUSIONS AND LESSONS LEARNED

## 5.1 Research Conclusions

Allergen and asthma triggers represent important health risks in the home environment, particularly for sensitive individuals and vulnerable populations, such as children. Molds, dust mites, and cockroaches are some of the major triggers commonly found in homes that influence respiratory outcomes. Through this Healthy Homes Technical grant, Duke University improved the understanding of both the distribution and the environmental, demographic, and social factors associated with these allergens and asthma triggers in homes in North Carolina. This area, and indeed, the entire Southeast has been the subject of relatively little research on indoor environmental health issues, despite having a climate very favorable to the growth and persistence of molds, dust mites, and cockroaches. We summarize the findings from this study below, as they relate to specific parts of our research and outreach efforts associated with this grant.

### *5.1.1 Bioaerosols in the Home*

- Indoor bioaerosol loads are strongly correlated with outdoor levels, regardless of air conditioning usage;

- Coastal areas appear to have lower overall fungal levels, but different fungal compositions compared to the Coastal Plain and the Piedmont;
- Forested land cover near homes can increase local fungal loads;
- Newer homes tend to have lower fungal loads, while homes with crawlspaces tend to have higher loads;
- Over half of the homes sampled experience some type of bioaerosol problem.
- Homes are less likely to have bioaerosol problems:

  a) During drought periods
  b) In areas lacking significant forest cover
  c) In agricultural areas
  d) If the home does not have a crawlspace.

### *5.1.2 Dustborne Allergens in the Home*

- Dust mite allergens are much more common than cockroach allergens in our study area.
- Levels of Der p1 allergens are higher in homes closer to forested areas, farther from agriculture, and had a strong seasonal component, tending to be lower during the warm, humid months in NC. They are also higher in areas of higher incomes, in homes that are partially carpeted and in older homes.
- Levels of the Der f1 allergen did not show significant seasonal variation, but are higher in homes closer to forested areas. They are higher in areas of higher median incomes and newer homes.
- Detection of the Bla g1 allergen was relatively infrequent in our study area and tended to occur more frequently in areas with newer homes, more renter-occupied housing, a higher proportion of Hispanics, and in homes where residents either garden or work in the agricultural industry.
- Almost 80% of our sampled homes had problems with at least one of these three allergens, with the two dust mite allergens responsible for the vast majority of these homes.
- Homes were at higher risk for dustborne allergen problems if they are in an urban area or are fully carpeted. Conversely, homes further from forested areas, as well as renter-occupied homes tend to be at lower risk for problems with dustborne allergen levels.

### *5.1.3 Combined Allergen Loads in Homes*

- Joint analysis of bioaerosol and dustborne allergens shows that a majority of homes have problems with both air and dustborne allergens.
- Homes located in forested areas appear to have a higher risk for problematic BABD levels, as do older homes. Conversely, cat or dog ownership or renter-occupied homes seem to be less likely to encounter problematic BABD levels.
- Our results do not suggest any disproportionate impact for homes in low income or high minority areas.

### *5.1.4 Role of Crawlspace*

- Crawlspaces can have a strong influence on indoor air quality.
- The temperature and humidity levels in crawlspaces generally provide an excellent environment for fungal growth.

- Human, animal, and weather-related disturbances of the crawlspace may stir up fungal spores, thus facilitating their transmission into the home environment.
- Transmission may occur through leaks between the home and the crawlspace, as well as via the HVAC system.

#### *5.1.5 Fire Risks in the Home*

- Wealthier neighborhoods have a greater likelihood of having homes with smoke detectors, thus lowering the risk for fires.
- A substantial portion of homes had smoke detectors that were not functioning.
- For homes with smoke detectors, newer homes are more likely to have functioning smoke detectors, while homes where Spanish is the primary language are less likely to have functioning smoke detectors. This means that the Hispanic community, particularly the newly-arrived persons, are at a greater risk for fires in the home. Outreach efforts to these households should be a priority.

### 5.2 Community Outreach and Education

Studies such as this present many opportunities to conduct outreach and education to individuals and communities. The following points characterize our outreach and education efforts:

- Maintaining the flexibility to have individual and community level outreach activities enhances one's ability to connect with a target population.
- Outreach, education, and training are most effective if delivered or negotiated through a network of partnerships that have developed over time and if they respect community expertise and needs.
- If participating in community events, developing relationships with community partners where they are treated as equal collaborators, rather than subjects, is crucial to gaining credibility with communities.
- Including a diverse range of stakeholders into one's set of partners is important for leveraging multiple resources for outreach, education, and training.
- In this project, leveraging resources across the Nicholas School of the Environment and Earth Sciences, the Division of Occupational and Environmental Medicine (OEM) within the Duke University Medical Center, and community partners provided an effective means to study and affect local environmental health risks.

While community needs are often highly diverse and specific, the suite of services offered through CEHI's research into indoor environmental exposures satisfies a fundamentally important need for quantifying the level of exposure to some of the most significant contaminants in the home. Through outreach activities that included a blend of communication, education, and training, CEHI used a variety of venues and technologies to address individual- and community-level concerns over potentially hazardous indoor substances.

## 6.0 FINANCIAL SUMMARY

6.1 Financial Summary

The total HUD cost of the project was $716,053.58. The total Match Amount (Duke Cost Share) was $86,625.00. The average HUD cost per month was $16,652.41, given 43 total project months. Discussions regarding lead hazard control, rehabilitation and relocation are not applicable for the scope of work of this project.

The activities associated with each cost were as follows:

Salary and fringe: A cumulative direct cost expense of $234,020.61 for salary and $47,794.47 for fringe was incurred to support the work of the following persons associated with the scope of work of the project; the project manager, the built environment sampling team for field data collection, the laboratory analysis team, the data management team, and the statistical data analysis team.

Supplies: A cumulative direct cost expense of $14,657.07 was incurred for sampling supply costs, laboratory supply costs, participant recruitment letters and follow-up postcards, and participant sampling report generation costs.

Travel: A cumulative direct cost expense of $16,161.44 was incurred for travel by the sampling team to 955 participants' homes in Chatham, Durham, New Hanover, Orange, Wayne, and Wilson counties and travel to HUD Office of Healthy Homes and Lead Hazard Control Grantee Conferences and Meetings.

Other: A cumulative direct cost expense of $78,188.69 was incurred for computer storage devices, data analysis and statistical software upgrades and licensing fees, and licensing training and certification costs. Also this includes telephone charges associated with the sampling team in the field and freight expenses associated with participant recruitment letters, postcards, and sampling report delivery.

The Contractor, Advanced Energy, incurred cumulative direct cost expense of $101,884.17 for their Phase 2 Crawl Space Sampling Project, which took place during the last 19 months of the total project. This represented an average monthly expense of $5,362.32 for the contractor. The expenses associated with this Phase 2 Crawl Space Sampling Project included home testing expenses in Durham, New Hanover, Wayne, and Wilson Counties, as well as expenses incurred for analysis of data from participant's home crawl spaces from data-loggers, temperature, and relative humidity. Also included are expenses related to homeowner report generation, data entry and analysis, and quality assurance checks. Expenses were incurred developing a communications tool in the form of a checklist, and the development of the crawl space characterization report.

Match amount, In-Kind Cost-Share: Direct costs of $56,250.00 and indirect costs of $30,375.00 were incurred during the project's built environment sampling period of 07/01/2003 to 9/30/2005. This represents a total average cost per month of $3208.33. The In-Kind Cost Share amount represents the contribution of Dr. Wayne Thomann's time and expertise performing the following functions for the environmental sampling project: meetings discussing project structure, participant recruitment strategies, data and laboratory analysis, management, and quality control measures; laboratory equipment maintenance and calibration; research design development; sampling protocol and standard operating procedures development and reassessment; and sample analytical research including microscopic analysis, counting, identification, and speciation of mold spores.

Indirect: A cumulative expense of $223,347.13 was incurred for indirect costs at the negotiated Duke rate of 54% of direct costs.

Please find the attached copy of the final voucher sent by Duke's Office of Sponsored Programs and financial report SF-269.

Final Section 3 (HUD 60002 Report) is not applicable.

| | HUD Amount | MATCH Amount | Total Budget | Cumulative Expense | Remaining Balance | % Variance |
|---|---|---|---|---|---|---|
| Salary | $ 225,005.00 | $ - | $ 225,005.00 | $ 234,020.61 | $ (9,015.61) | -4% |
| Fringe | $ 45,457.00 | $ - | $ 45,457.00 | $ 47,794.47 | $ (2,337.47) | -5% |
| Supplies | $ 34,000.00 | $ 56,250.00 | $ 90,250.00 | $ 70,907.07 | $ 19,342.93 | 21% |
| Travel | $ 16,227.00 | $ - | $ 16,227.00 | $ 16,161.44 | $ 65.56 | 0% |
| Contract | $ 120,000.00 | $ - | $ 120,000.00 | $ 101,884.17 | $ 18,115.83 | 15% |
| Other | $ 72,200.00 | $ - | $ 72,200.00 | $ 78,188.69 | $ (5,988.69) | -8% |
| Indirect | $ 225,660.00 | $ 30,375.00 | $ 256,035.00 | $ 253,722.13 | $ 2,312.87 | 1% |
| **Total** | **$ 738,549.00** | **$ 86,625.00** | **$ 825,174.00** | **$ 802,678.58** | **$ 22,495.42** | **3%** |

## 7.0 References

(1) Thermo Electron Corporation, Two Stage Viable Impactor. 2004. http://www.thermo.com/com/cda/product/detail/1,1055,22538,00.html.
(2) Willeke, K.; Macher, J. Air sampling. In *Bioaerosols: assessment and control*; Macher, J., Ed.; American Conference of Governmental Industrial Hygienists: Cincinnati, Ohio, 1999; pp 1 v. (various pagings): ill., 28 cm.
(3) Larone, D. H. *Medically important fungi*; 4th ed.; ASM Press: Washington, D.C., 2002.
(4) Carlile, M. J.; Watkinson, S. C.; Gooday, G. W. *The fungi*; 2nd ed.; Academic Press: San Diego, 2001.
(5) Strachan, D. P.; Flannigan, B.; McCabe, E. M.; McGarry, F., Quantification of airborne moulds in the homes of children with and without wheeze. **1990**, 382-387.
(6) Strachan, D. P.; Flannigan, B.; McCabe, E. M.; McGarry, F., Quantification of airborne moulds in the homes of children with and without wheeze. *Thorax* **1990**, *45*, 382-387.
(7) Shelton, B. G.; Kirkland, K. H.; Flanders, W. D.; Morris, G. K., Profiles of airborne fungi in buildings and outdoor environments in the United States. *Applied and Environmental Microbiology* **2002**, *68*, 1743-1753.
(8) Dharmage, S.; Bailey, M.; Raven, J.; Abeyawickrama, K.; Cao, D.; Guest, D.; Rolland, J.; Forbes, A.; Thien, F.; Abramson, M.; Walters, E. H., Mouldy houses influence symptoms of asthma among atopic individuals. *Clinical and Experimental Allergy* **2002**, *32*, 714-720.
(9) McCune, B.; Grace, J. B. *Analysis of Ecological Communities*; MjM Software Design: Gleneden Beach, OR, 2002.
(10) Li, D. W.; Kendrick, B., Functional and causal relationships between indoor and outdoor airborne fungi. *Canadian Journal of Botany-Revue Canadienne De Botanique* **1996**, *74*, 194-209.
(11) Chew, G. L.; Rogers, C.; Burge, H. A.; Muilenberg, M. L.; Gold, D. R., Dustbourne and airborne fungal propagules represent a different spectrum of fungi with differing relations to home characteristics. *Allergy* **2003**, *58*, 13-20.
(12) Takahashi, T., Airborne Fungal Colony Forming Units in Outdoor and Indoor Environments in Yokohama, Japan. *Mycopathologia* **1997**, *139*, 23-33.
(13) Ren, P.; Jankun, T.; Leaderer, B., Comparisons of seasonal fungal prevalence in indoor and outdoor air and in house dusts of dwellings in one Northeast American county. *Journal of Exposure Analysis and Environmental Epidemiology* **1999**, *9*, 560-568.
(14) Helbling, A., Fungi as allergens. *Allergologie* **2003**, *26*, 482-489.
(15) Lehrer, S. B.; Hughes, J. M.; Altman, L. C.; Bousquet, J.; Davies, R. J.; Gell, L.; Li, J.; Lopez, M.; Malling, H. J.; Mathison, D. A.; Sastre, J.; Schultzewerninghaus, G.; Schwartz, H. J., Prevalence of Basidiomycete Allergy in the USA and Europe and Its Relationship to Allergic Respiratory Symptoms. *Allergy* **1994**, *49*, 460-465.
(16) Horner, W. E.; Hughes, J. M.; Lopez, M.; Lehrer, S. B., Basidiomycete skin test reactivity is a risk factor for asthma. *Pediatric Asthma Allergy & Immunology* **2000**, *14*, 69-74.
(17) Dales, R. E.; Cakmak, S.; Judek, S.; Dann, T.; Coates, F.; Brook, J. R.; Burnett, R. T., Influence of outdoor aeroallergens on hospitalization for asthma in Canada. *Journal of Allergy and Clinical Immunology* **2004**, *113*, 303-306.
(18) Cakmak, S.; Dales, R. E.; Burnett, R. T.; Judek, S.; Coates, F.; Brook, J. R., Effect of airborne allergens on emergency visits by children for conjunctivitis and rhinitis. *Lancet* **2002**, *359*, 947-948.
(19) Institute of Medicine *Clearing the air: asthma and indoor air exposures*; National Academy Press: Washington, DC, 2000.
(20) Etzel, R. A.; Balk, S. J. *Pediatric Environmental Health*; 2nd ed.; American Academy of Pediatrics: Elk Grove Village, 2003.

(21) Arlian, L. G.; Morgan, M. S., Biology, ecology, and prevalence of dust mites. *Immunology And Allergy Clinics Of North America* **2003**, *23*, 443-+.
(22) Colloff, M. J., Taxonomy and identification of dust mites. *Allergy* **1998**, *53*, 7-12.
(23) van Strien, R. T.; Gehring, U.; Belanger, K.; Triche, E.; Gent, J.; Bracken, M. B.; Leaderer, B. P., The influence of air conditioning, humidity, temperature and other household characteristics on mite allergen concentrations in the northeastern United States. *Allergy* **2004**, *59*, 645-652.