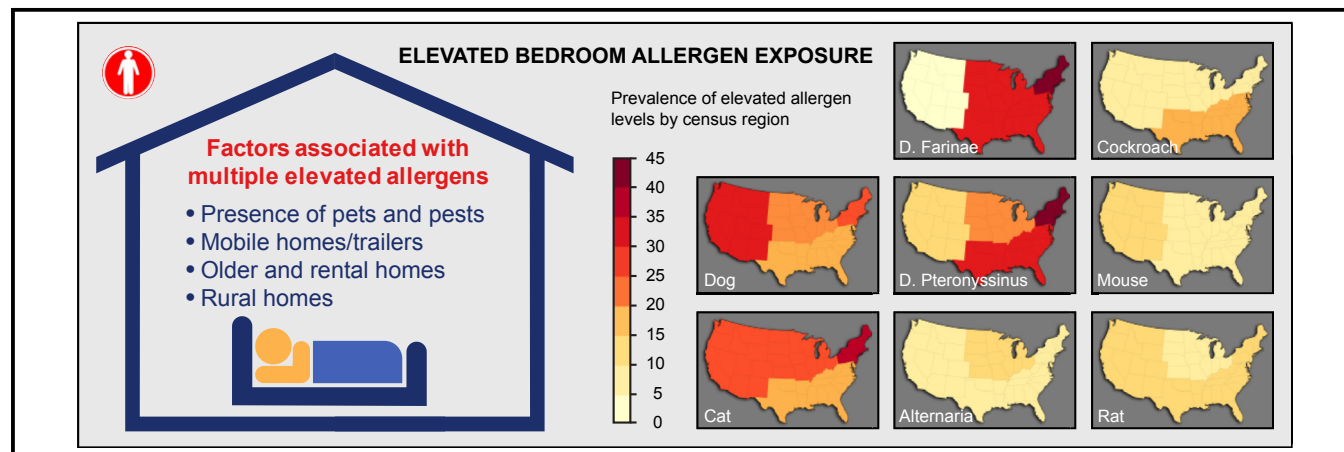


Bedroom allergen exposures in US households

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GRAPHICAL ABSTRACT



Background: Bedroom allergen exposures contribute to allergic disease morbidity because people spend considerable time in bedrooms, where they come into close contact with allergen reservoirs.

Objective: We investigated participant and housing characteristics, including sociodemographic, regional, and climatic factors, associated with bedroom allergen exposures in a nationally representative sample of the US population.

Methods: Data were obtained from National Health and Nutrition Examination Survey 2005-2006. Information on participant and housing characteristics was collected by using questionnaires and environmental assessments. Concentrations of 8 indoor allergens (Alt a 1, Bla g 1, Can f 1, Fel d 1, Der f 1, Der p 1, Mus m 1, and Rat n 1) in dust vacuumed from nearly 7000 bedrooms were measured by using immunoassays.

Exposure levels were classified as increased based on percentile (75th/90th) cutoffs. We estimated the burden of exposure to

multiple allergens and used multivariable logistic regression to identify independent predictors for each allergen and household allergen burden.

Results: Almost all participants (>99%) had at least 1 and 74.2% had 3 to 6 allergens detected. More than two thirds of participants (72.9%) had at least 1 allergen and 18.2% had 3 or more allergens exceeding increased levels. Although exposure variability showed significant racial/ethnic and regional differences, high exposure burden to multiple allergens was most consistently associated with the presence of pets and pests, living in mobile homes/trailers and older and rental homes, and living in nonmetropolitan areas.

Conclusions: Exposure to multiple allergens is common. Despite highly variable exposures, bedroom allergen burden is strongly associated with the presence of pets and pests. (J Allergy Clin Immunol 2017;■■■:■■■-■■■.)

Key words: Allergen, indoor, exposure, home, allergy

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The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the RDC, the NCHS, or the US Centers for Disease Control and Prevention.

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Abbreviations used

LLOD:	Lower limit of detection
MARIA:	Multiplex Array for Indoor Allergens
NCHS:	National Center for Health Statistics
NHANES:	National Health and Nutrition Examination Survey
NSLAH:	National Survey of Lead and Allergens in Housing
PIR:	Poverty index ratio
SES:	Socioeconomic status
sIgE:	Specific IgE

Indoor allergen exposures are important risk factors of allergic respiratory disease because people spend a large portion of their time indoors, especially at home.¹⁻³ Although the relationship between allergen exposures and development of allergic sensitization and disease is complex and not fully understood,¹ indoor allergens can trigger and exacerbate asthma and allergy symptoms in sensitized subjects.^{1,2,4-8} Despite extensive research, most indoor allergen studies have focused on selected high-risk populations (eg, asthmatic subjects, children, and inner-city populations), single allergens, or both.^{2,9-11} Recently released data from the National Health and Nutrition Examination Survey (NHANES) provide the largest resource to date for assessment of indoor allergen exposures in a nationally representative sample of the US population,¹² following the National Survey of Lead and Allergens in Housing (NSLAH), which was conducted on a much smaller scale in 1998-1999.¹³ NHANES 2005-2006 assessed residential indoor allergen levels in bedroom dust collected from nearly 7000 US households.

Bedrooms are often considered an important site for allergen exposure not only because of the time spent in bed but also because of the close proximity of allergen reservoirs (eg, bedding) to a person's breathing zone and associated reservoir disturbances.¹⁴ Recent studies demonstrate that a significant fraction of airborne particles, which are resuspended by human movements in bed, can be inhaled during sleep.^{15,16} Although residential exposures can vary spatially and temporally, several studies link bedroom allergen exposures to allergic sensitization and disease morbidity,¹⁷ especially among those who are exposed to increased levels of the allergen or allergens to which they are sensitized.⁴⁻⁷

To advance our knowledge of the prevalence and determinants of indoor allergen exposures, we investigated the importance of different sociodemographic and housing factors in residential allergen exposures. This article provides the most comprehensive report on bedroom allergen exposures in US households, estimating the exposure burden to individual and multiple allergens and identifying independent predictors of these exposures. To date, no study has provided such detailed information on how allergen levels vary by regional and climatic factors, as well as by level of urbanization. Because NHANES 2005-2006 is the first large population-based study to enable comparisons between exposure and sensitization patterns in the general US population, we also discuss sociodemographic similarities and differences between allergen exposures and the previously reported sensitization patterns.¹⁸

METHODS**Study data and design**

Data were collected as part of NHANES 2005-2006, which used a complex multistage probability sampling design to select a sample of the civilian, noninstitutionalized US population. The survey oversampled adolescents (aged 12-19 years), elderly persons (aged ≥ 60 years), African Americans, Mexican Americans, and low-income persons to ensure adequate samples for subgroup analyses. Information on participant and housing characteristics was obtained by using questionnaires,¹⁹⁻²¹ as well as environmental assessments (eg, room temperature and relative humidity were assessed with a digital hygrothermometer).²²

NHANES 2005-2006 included a component that assessed indoor allergen levels in reservoir dust samples collected from participants' bedrooms. A detailed description of the study procedures is available in the NHANES Allergen Dust Collection Procedures Manual.²² Because of delays in the laboratory analysis phase of this component, dust data were not available until 2014. Our data analysis is limited to participants with dust data available ($n = 6963$).

Table E1 in this article's Online Repository at www.jacionline.org shows selected population characteristics of the NHANES 2005-2006 participants. To protect participant confidentiality, all data analysis using restricted and not publicly available variables (census region, level of urbanization, climate region, and presence of children in the household) was conducted at the National Center for Health Statistics (NCHS) Atlanta Research Data Center. All restricted variables were provided, created, or both by the NCHS. The climate regions were determined based on the guidelines of the US Department of Energy Building America Program, which use heating degree days, average temperatures, and precipitation to differentiate each region.²³ To avoid data suppression caused by small cell sizes, 8 US climate regions were aggregated into 4 categories: subarctic/very cold/cold; mixed-humid/marine; hot-humid; and mixed-dry/hot-dry.

The survey protocol was approved by the NCHS Ethics Review Board,²⁴ and written informed consent was obtained from all participants. Information on the NHANES survey design and implementation can be found at http://www.cdc.gov/nchs/nhanes/survey_methods.htm.²⁵

Exposure assessment

Participants aged 1 year and older were eligible for dust allergen testing. Dust samples were collected from each participant's bed and bedroom floor with a Sanitare Model 3683 Vacuum Cleaner and a Mitest Dust Collector (Indoor Biotechnologies, Charlottesville, Va). For a combined sample, each sampling location (1 square yard) was vacuumed for 2 minutes, and allergen levels were assessed with immunoassays. Concentrations of dog (Can f 1), dust mite (Der f 1 and Der p 1), cat (Fel d 1), *Alternaria alternata* (Alt a 1), mouse (Mus m 1), and rat (Rat n 1) allergens were assessed with the Multiplex Array for Indoor Allergens (MARIA; Indoor Biotechnologies), whereas concentrations of cockroach allergen (Bla g 1) were measured with an ELISA.¹² For allergens assessed with MARIA, the lower limit of detection (LLOD) varied from 0.002 to 0.013 $\mu\text{g/g}$. The lowest LLOD for Bla g 1 was 0.002 U/g. Fill values equal to the allergen-specific LLOD divided by the square root of 2 were used for samples less than the LLOD to maximize the number of samples in the analyses.¹² Details of the laboratory methods and quality control procedures are published elsewhere.^{26,27}

Statistical analysis

Allergen concentrations were dichotomized to high and low to medium levels to estimate exposure to increased allergen levels and the burden to multiple allergens. Because clinically relevant thresholds have not been established for all measured allergens, we used percentile cutoffs to ensure a consistent analytic approach across all allergens. For allergens that had relatively nonskewed distributions, allergen exposures were classified as increased if the allergen concentration exceeded the 75th percentile (Can f 1, 8.472 $\mu\text{g/g}$; Fel d 1, 6.369 $\mu\text{g/g}$; Der f 1, 0.338 $\mu\text{g/g}$; and Der p 1, 0.219 $\mu\text{g/g}$). For allergens with skewed distributions, a cutoff of the 90th percentile was

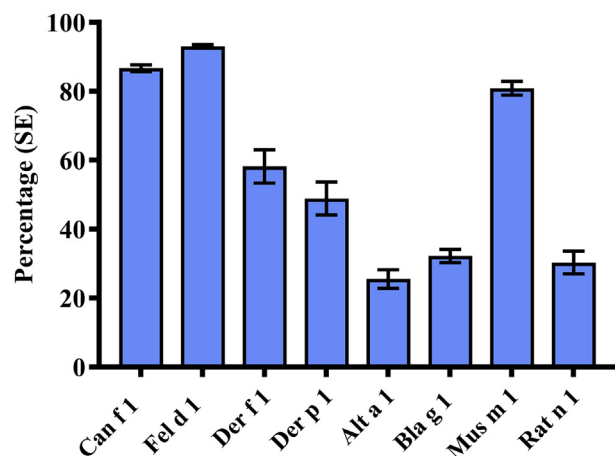


FIG 1. Prevalence $\pm$ SE of exposure to detectable bedroom allergen levels in the US population.

used to differentiate exposure levels (Alt a 1, 0.009 μ g/g; Bla g 1, 1.778 U/g; Mus m 1, 0.238 μ g/g; and Rat n 1, 0.013 μ g/g). To evaluate the overall allergen burden, we created 4 separate outcomes that reflected different exposure levels. Exposure burden was classified as high when (1) 3 or more allergens exceeded increased levels (Multiple Elevated Exposures) or (2) 7 or more allergens were greater than detection limits and at least 1 allergen exceeded increased levels (Multiple Detectable Exposures). Exposure burden was considered low to medium when none of the allergens exceeded increased levels (No Elevated Exposures) and low when 2 or fewer allergens were detected and none of the allergens exceeded increased levels (Low Exposure).

We performed logistic regression analyses to identify independent predictors for individual allergen exposures and for the 4 allergen burden-related outcomes. First, all potential participant- and housing-related variables were evaluated by using bivariate analyses. Of these variables (age; sex; race/ethnicity; poverty index ratio [PIR]²¹; census and climate region; level of urbanization; housing type; year home was constructed; tenure; length of residency; number of household members; presence of pets [cats/dogs], cockroaches, mildew/musty smell, children, smokers, or mattress covers; reported pet avoidance; type of floor covering; room temperature; and relative humidity), we selected those with *P* values of less than .25 for inclusion in the regression analysis. We chose a data-driven modeling approach and used backward elimination for model selection; starting from the full model, variables with the highest *P* value (Wald *F*) were dropped until all remaining predictors in each model had *P* values of less than or equal to .05. The climate and census region variables were interrelated and thus were modeled separately. Because climate region was not an independent predictor for increased allergen levels, except for Der f 1, complete modeling results are presented only for census region.

All descriptive statistics and predictive modeling were performed with SAS software (version 9.3; SAS Institute, Cary, NC). Cluster analysis was conducted with the R system for statistical computing (version 2.10.1). The sampling weights and design variables were applied to all analyses to obtain unbiased national prevalence and variance estimates.²⁵ Separate dust allergen examination subsample weights were used to account for selective nonresponse and any missing laboratory data.¹²

RESULTS

Distributions of allergen levels

Of the NHANES 2005-2006 participants with available dust data, 98.1% (*n* = 6832) had data for each of the 8 allergens. Fig 1 shows percentages of participants with detectable levels of allergens. Cat (Fel d 1, 93.0%), dog (Can f 1, 86.7%), and mouse (Mus m 1, 80.9%) were the most commonly detected allergens, followed by dust mite allergens (Der f 1, 58.2%; Der p 1,

48.9%). More detailed information on the distributional characteristics and clustering patterns is presented in Fig E1 and Tables E2 and E3 in this article's Online Repository at www.jacionline.org.

Overall burden to multiple allergens

Exposure to multiple allergens was common. Detectable levels of allergens were present in almost all bedrooms (>99%), and more than 90% of participants had at least 3 allergens detected (Fig 2, A). Of the participants, 15.8% had 7 or more allergens detected and at least 1 allergen exceeding increased levels. The majority of the participants were exposed to increased allergen levels; more than two thirds of participants (72.9%) had at least 1 allergen and 18.2% had 3 or more allergens exceeding increased levels (Fig 2, B). Only 6.4% of the participants had a low allergen burden (≤ 2 allergens detected, with no allergens exceeding increased levels) in their bedrooms.

Individual allergen levels in relation to participant and housing characteristics

The bar graphs in Fig E2 in this article's Online Repository at www.jacionline.org illustrate the prevalence of increased allergen levels across categories of the variables of interest. Of the participants' characteristics, race/ethnicity and family PIR were most consistently associated with increased allergen levels. Non-Hispanic black subjects had the lowest prevalence of increased dog, cat, and *Alternaria* allergen levels, whereas increased cockroach allergen levels were least prevalent among non-Hispanic white subjects. Increased pet allergen levels were detected most frequently in more affluent households, whereas increased Der f 1 levels were most common in middle-income households, and increased levels of Der p 1, cockroach, and mouse allergens were most prevalent in low-income homes. Allergen levels were also associated with the participant's age and the presence of children in the household. For example, increased Der p 1 and mouse allergen levels were more common among children than adults, whereas increased Der f 1 levels were least prevalent in households with young children. Female subjects were more likely to have increased levels of cat and *Alternaria* allergens in their bedrooms.

Allergen levels varied by region and climatic factors (Fig 3 and see Fig E3 in this article's Online Repository at www.jacionline.org). Increased cockroach allergen levels were most prevalent in hot-humid and mixed-humid/marine climates, particularly in the Southern region. Dust mite allergen levels were strongly influenced by region and climate. Although increased dust mite allergen levels were most prevalent in the Northeastern region, climatic factors influenced allergen levels. Der p 1 levels were increased most frequently in hot-humid areas, whereas increased Der f 1 levels were most common in mixed-hot/marine climates. Pet and dust mite allergen levels differed significantly by level of urbanization (see Fig E2). Increased dog allergen levels were less frequently found in nonmetropolitan homes, whereas the prevalence of increased cat allergen levels was least common in large central metropolitan areas. The prevalence of increased dust mite allergen levels decreased with increasing level of urbanization.

Multifamily homes were less likely to have increased allergen levels, except for mouse and cockroach allergens (see Fig E2). For

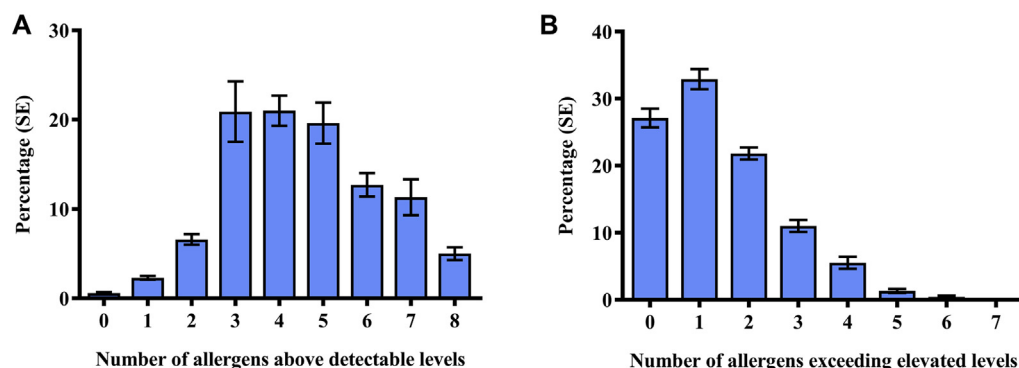


FIG 2. Exposure to multiple allergens in bedrooms. Percentages $\pm$ SEs of NHANES 2005-2006 participants with detectable (A) and increased (B) levels of allergens by numbers of allergens exceeding allergen-specific thresholds (limit of detection, 75th/90th percentile). Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile.

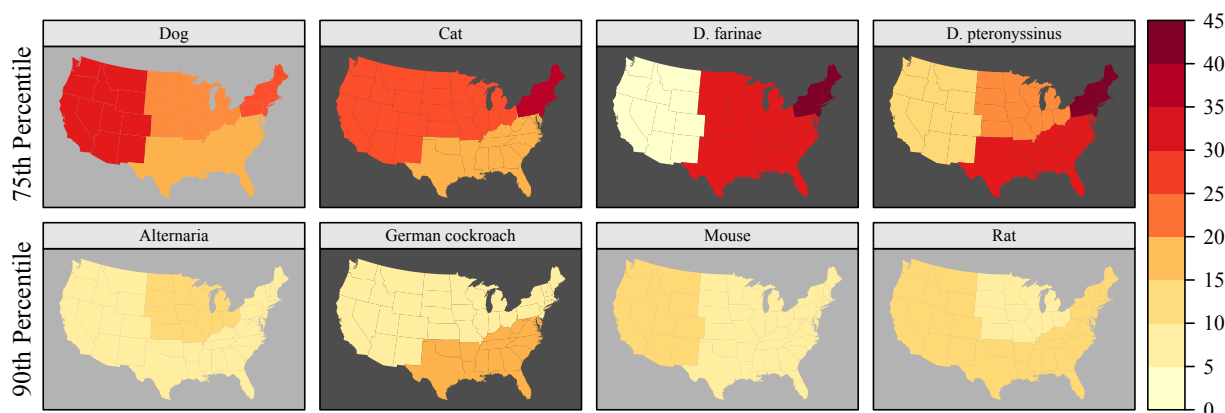


FIG 3. Prevalence of increased allergen levels by census region. Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. The dark background color in the map indicates statistically significant differences ($P < .05$) across US census regions (Northeast, Midwest, South, and West).

most allergens, the prevalence of increased levels was highest in mobile homes. Increased dust mite allergen levels were prevalent in older homes, and the prevalence of increased allergen levels tended to increase with increasing years of residency. Increased pet allergen levels were more common in resident-owned homes and less crowded households, whereas increased Der p 1, cockroach, and mouse allergen levels were more prevalent in rental homes. The presence of pets and pests was strongly associated with increased levels of Can f 1, Fel d 1, and Bla g 1. However, the presence of cockroaches was also associated with increased Der p 1 and rodent allergen levels. Increased cat, rodent, and dust mite allergen levels were less prevalent in households that reported pet avoidance measures because of the participant's allergies or asthma. Reported mildew and/or musty smell in the home was associated with increased Der p 1 levels, whereas increased Der f 1 levels were strongly associated with the presence of carpeting. Only dust mite allergen levels were influenced by room temperature and relative humidity. Having an impermeable mattress cover was associated with a lower prevalence of increased allergen levels, particularly for mouse allergen. The presence of smokers, which is often associated

with lower socioeconomic status (SES),^{9,28} was considered a potential predictor of increased Der p 1, Alt a 1, and Bla g 1 levels, but it did not remain as an independent predictor for any allergens.

Independent predictors of individual allergen exposures

Fig 4 summarizes results from the predictor modeling for each allergen. In the heat map the direction and strength of the associations are indicated by color, and numeric odds ratios for the predictors are presented in Table E4 in this article's Online Repository at www.jacionline.org. Race/ethnicity, family PIR, and level of urbanization were the most consistent predictors of individual allergen levels, whereas the strongest associations were observed between increased pet allergen levels and the presence of cats/dogs. The participant's age and sex remained independent predictors for increased dust mite, mouse, cat, and *Alternaria* allergen levels. Region and climatic factors predicted only increased dust mite levels. The odds of having increased Der f 1 and Der p 1 levels were highest in the Northeastern and Southern regions. Climate region was an independent predictor for

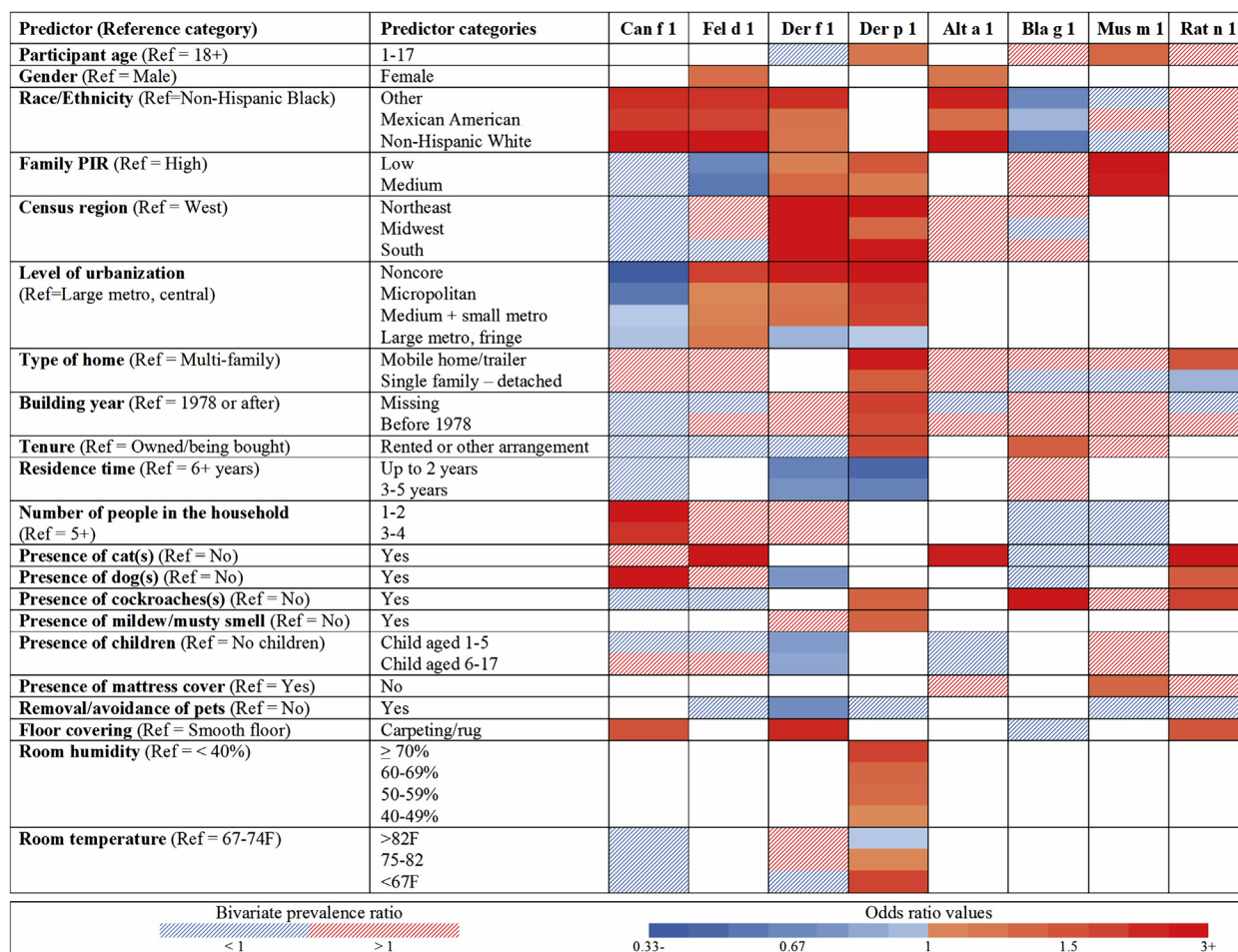


FIG 4. Independent predictors of increased allergen levels. Odds ratios from multivariable regression models are presented in Table E4. For the independent predictors, the solid red/blue color indicates the direction of the associations (red increasing and blue decreasing) when each of the participant/housing characteristic categories were compared with the reference category adjusting for the other independent predictor variables in the model. *Dashed areas* indicate participant/housing characteristics included in initial prediction models based on bivariate analysis ($P < .25$, Fig E2). Metropolitan counties are subdivided based on the population of their metropolitan statistical area (MSA): large (central, fringe) for an MSA population of 1 million or more, medium for an MSA population of 250,000 to 999,999, and small for an MSA population of less than 250,000. Nonmetropolitan counties not defined as micropolitan are considered to be noncore and are thought of as the most rural areas.

increased Der f 1 levels; compared with mixed-dry/hot-dry climates, living in mixed-humid/marine or hot-humid climates increased the odds of increased Der f 1 levels 3- to 4-fold (data not shown). Overall, housing characteristics were most frequently associated with increased Der p 1 levels, but the presence of carpeting increased the odds of having increased levels of several allergens. The presence of pets and cockroaches increased Can f 1, Fel d 1, and Bla g 1 levels and was associated with increased levels of other allergens. Interestingly, reported pet avoidance was associated with lower odds of having increased Der f 1 levels and did not predict lower pet allergen levels in the bedroom.

Allergen burden in relation to participant and housing characteristics

The bar graphs in Fig E4 in this article's Online Repository at www.jacionline.org illustrate allergen burden across categories of

the studied characteristics. Allergen burden varied significantly by race/ethnicity. Non-Hispanic black subjects were more likely to have low (≤ 2 detectable allergens, with no increased exposures) or low to medium (no increased exposures) allergen burden than other racial/ethnic groups. Although children were less likely to have low allergen burden than adults, low allergen burden was more prevalent in homes with children aged 1 to 5 years than in those with older children. Having multiple detectable allergens with at least 1 exceeding the elevation threshold was more common among female than male subjects. Although allergen burden was not strongly influenced by SES (ie, PIR), regional differences were apparent (Fig 5). Low to medium exposure burden was most prevalent in the Western region, whereas the highest prevalence of multiple increased exposures was found in the Northeastern region. However, the number of detectable allergens was highest in the Midwest region. Allergen burden did not differ significantly across the 4 climate regions (see Fig E5 in this article's Online Repository at www.jacionline.org).

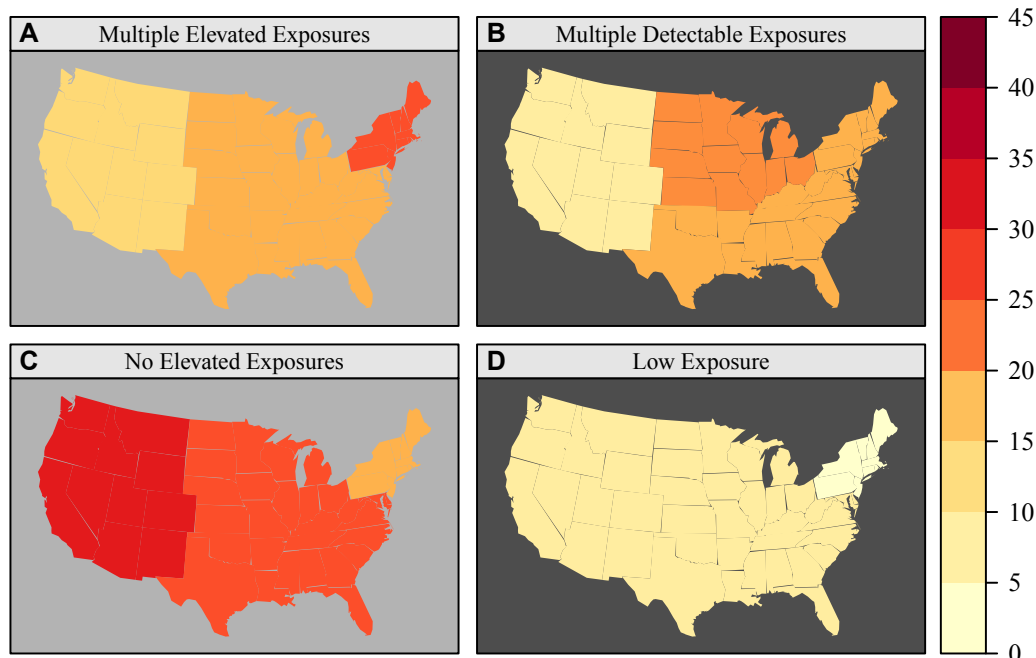


FIG 5. Prevalence of allergen burden by census region. Allergen burden outcomes: *Multiple Elevated Exposures* (≥ 3 allergens at increased levels) (A); *Multiple Detectable Exposures* (≥ 7 allergens $>$ limit of detection, ≥ 1 allergens at increased levels) (B); *No Elevated Exposures* (0 allergens at increased levels) (C); and *Low Exposure* (≤ 2 allergens $>$ limit of detection, 0 allergens at increased levels) (D). Can f 1, Fel d 1, Der p 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. The dark background color in the map indicates statistically significant differences ($P < .05$) across census regions (Northeast, Midwest, South, and West).

Compared with metropolitan areas, nonmetropolitan areas were more likely to have several allergens at increased levels.

Of the housing characteristics, type and age of housing were associated consistently with allergen burden (see Fig E4). Allergen burden was highest in mobile homes and lowest in multifamily housing. The prevalence of high allergen burden increased with increasing age of the home. The presence of pets and pests contributed strongly to high allergen burden. The presence of carpeting and mildew/musty smell was associated with a greater likelihood of having higher allergen burden, whereas low allergen burden was more prevalent in homes with fewer occupants and low humidity. Although allergen burden tended to be higher in homes of smokers and lower among those who reported avoiding pets, neither of the variables was an independent predictor of allergen burden.

Independent predictors of allergen burden

Fig 6 summarizes modeling results, showing the direction and strength of the associations by color, whereas odds ratios for the predictors are presented in Table E5 in this article's Online Repository at www.jacionline.org.

Race/ethnicity and presence of pets and pests predicted allergen burden most consistently. Although low to medium allergen burden was more prevalent among adults than children, the presence of young children aged 1 to 5 years was associated with low allergen burden. Female subjects tended to be exposed to a greater number of allergens than male subjects. Allergen burden was strongly affected by census region and level of urbanization. For example, the odds of having high allergen

burden significantly increased with decreasing level of urbanization. High allergen burden was prevalent in mobile homes/trailers, as well as older and rental homes. Reported mildew and/or musty smell and presence of carpeting increased the odds of exposure to multiple allergens. Low allergen burden was most prevalent in homes with few occupants. Increased humidity levels were associated with reduced odds of having low to medium allergen burden.

DISCUSSION

The role and characteristics of residential indoor allergen exposures have been investigated in numerous studies, but only 2, NHANES 2005-2006 and NSLAH, have examined exposure characteristics and variability in nationally representative samples of the US population. Although NSLAH advanced our understanding of the prevalence and determinants of indoor allergen exposures,²⁹⁻³⁴ NHANES 2005-2006 provided a much larger cohort to support enhanced power and precision associated with subgroup analyses on a national scale. NHANES data demonstrated that individual allergen levels and allergen burden varied significantly by participant and housing characteristics; however, climatic conditions and SES were associated only with individual allergen levels and not with allergen burden. High allergen burden was most consistently associated with the presence of pets and pests and living in mobile homes/trailers, older and rental homes, and nonmetropolitan areas. Compared with the previously published sensitization patterns in this population,¹⁸ allergen exposures show distinct differences by

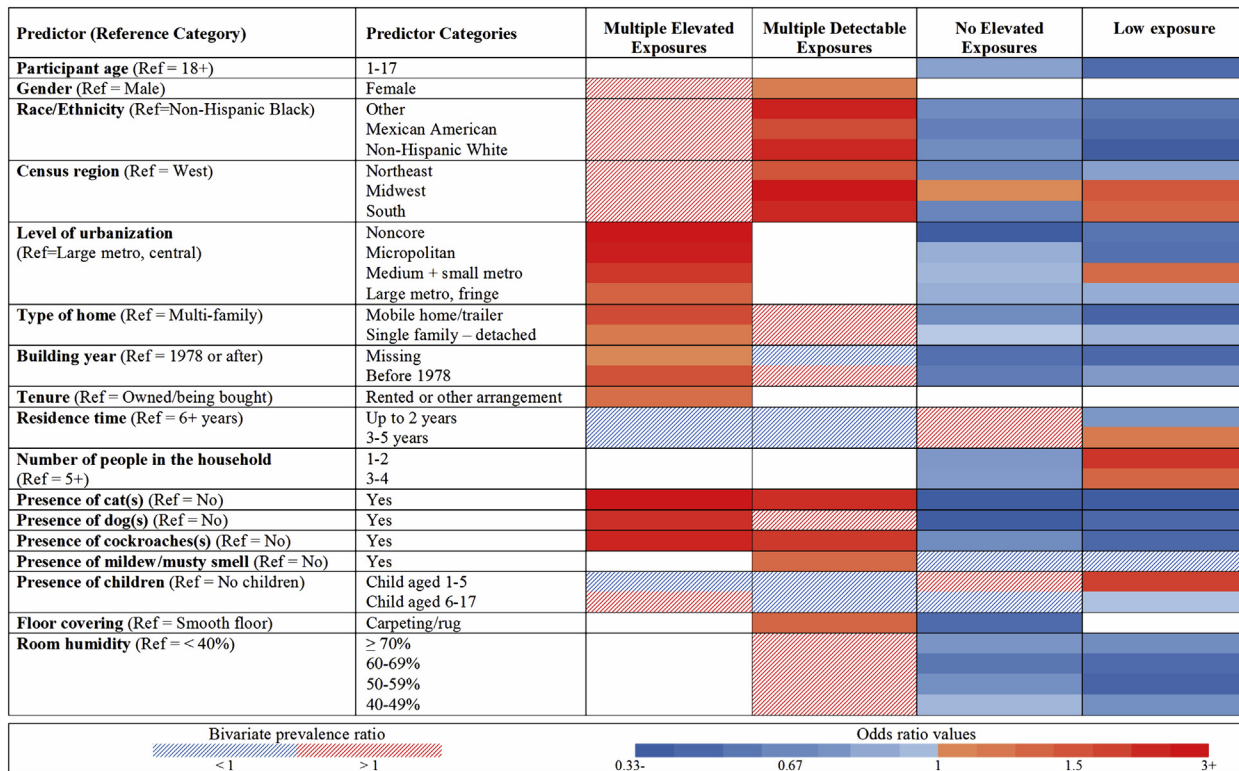


FIG 6. Independent predictors of allergen burden. Allergen burden outcomes: *Multiple Elevated Exposures* (≥ 3 allergens at increased levels); *Multiple Detectable Exposures* (≥ 7 allergens $>$ limit of detection, ≥ 1 allergens at increased levels); *No Elevated Exposures* (0 allergens at increased levels); and *Low Exposure* (≤ 2 allergens $>$ limit of detection, 0 allergens at increased levels). Odds ratios from multivariable regression models are presented in Table E5. For independent predictors, the solid red/blue color indicates the direction of the associations (red increasing and blue decreasing) when each of the participant/housing characteristic categories were compared with the reference category adjusting for other independent predictor variables in the model. *Dashed areas* indicate participant/housing characteristics included in initial prediction models based on bivariate analysis ($P < .25$, Fig E4).

sex, race/ethnicity, and level of urbanization, as highlighted in the discussion.

Agreeing with NSLAH,³³ exposure to multiple allergens was common. Allergens were detected ubiquitously, practically in every home, and in most homes, allergens were found at increased levels. However, because of methodological differences (eg, use of different types of antibodies and standards), it is difficult to make direct quantitative comparisons between the surveys. Allergens were assessed with individual ELISAs in NSLAH, whereas a more sensitive multiplex assay, MARIA,³⁵ was used to quantify most allergens in NHANES 2005-2006. In NSLAH *A alternata* and mouse allergens were also measured with polyclonal antibodies, which have higher potential for cross-reactivity. Indeed, polyclonal antibodies against *A alternata* have been found to cross-react with other fungi.³⁶

Allergen clustering patterns were largely similar in both surveys.³³ Rat allergen, which was not measured in NSLAH, showed very strong clustering with other allergens at high levels, reflecting high overall allergen burden in the home. In contrast, clustering of allergens showed less distinct patterns than allergen-specific IgEs (sIgE) in NHANES 2005-2006.¹⁸ Although interesting, this is not completely unexpected, given that additional factors, including host susceptibility, other environmental exposures, and biological cross-reactivity, influence sIgE clustering.

Participant's race/ethnicity was strongly associated with individual allergen levels and allergen burden, supporting the NSLAH findings.³³ Although racial differences in *Alternaria* species and pet allergen exposures might explain why non-Hispanic black subjects were more likely to have lower allergen burden than other groups, the finding is contradictory to the observed racial disparities in sensitization. Several studies have demonstrated that allergic sensitization and disease rates are higher in non-Hispanic black subjects than in other groups.^{18,37-39} In NHANES 2005-2006 racial/ethnic exposure patterns differed from patterns observed in allergic sensitization,¹⁸ except for cockroach. Among non-Hispanic black subjects, both exposure and sensitization to cockroach allergen were more prevalent than in other groups.

Children were less likely than adults to have low allergen burden in their homes. However, the odds of having low allergen burden were 2-fold greater among homes with children aged 1 to 5 years compared with those without children. Because NHANES did not collect information on cleaning frequency, it remains unclear whether this relates to more frequent cleaning activities in homes with young children. Yet the presence of young children, as well as reported pet avoidance measures, conferred lower odds of having increased Der f 1 levels. On the other hand, reported pet avoidance did not decrease the odds of having increased pet allergen levels or high allergen burden in the bedroom.

Although exposure to pets, especially in early life, can have a protective effect on the development of allergic sensitization and asthma,⁴⁰⁻⁴² decreasing exposure is advisable for those who are sensitized to pet allergens.^{5,40} In fact, national data suggest that exposure to increased dog and cat allergen levels in the bedroom is associated with excess asthma attacks and emergency care visits among pet-sensitive asthmatic subjects in the United States.⁴³

Although positive sIgE test results and increased sIgE levels are reported more commonly among male than female subjects,¹⁸ the odds of being exposed to multiple allergens were higher for female than male subjects. In particular, *Alternaria* and cat allergen levels were increased among female subjects. The results might reflect behavioral differences related to pet ownership. *Alternaria* spore concentrations are often found to be greater outdoors than indoors,⁴⁴ which might explain why Alt a 1 was detected at much lower levels than Fel d 1. Previous studies support that the presence of pets is associated with higher residential fungal levels.^{34,45,46} Although pets can transport outdoor allergens on their fur, potential indoor sources cannot be ruled out.

SES was associated with individual allergen levels, agreeing with published data.^{29,31,34,47} Exposure and sensitization patterns showed similarities, most consistently for pet and cockroach allergens. However, PIR, an indicator of SES, was not an independent predictor of allergen burden, suggesting that residential allergen burden might not vary significantly across different socioeconomic groups. Although allergen burden in the home can differ depending on which allergens are measured, another study has reported that the risk of having at least 1 allergen at increased levels might not vary between high- and low-poverty area homes.⁴⁷

Regional variation was apparent for allergen exposures and burden. Dust mite allergen levels, which are not necessarily highly correlated and tend to differ by housing conditions and characteristics (eg, humidity levels, age, and type of house),^{10,30,48} also exhibited substantial regional differences. Consistent with NSLAH, the prevalence of increased levels of dust mite allergens was significantly lower in the Western region compared with the Northeastern and Southern regions in the United States.³⁰ In NHANES 2005-2006, regional exposure and sensitization patterns showed similarities for dust mite and cockroach allergens.¹⁸ For dust mites, increased exposure levels, as well as the prevalence of sensitization and increased sIgE levels, were highest in the Northeast and South.¹⁸ Exposure and sensitization to cockroach allergen tended to be highest in the South,¹⁸ although census region was not an independent predictor for increased cockroach allergen levels. The NHANES 2005-2006 data suggested that allergen burden might vary both across and within census regions. For example, participants in the South were less likely to have low to medium exposures and more likely to have multiple detectable exposures than those living in the West. On the other hand, although multiple detectable exposures were more prevalent in the Midwest than in the western US, participants in the Midwest had higher odds of having low allergen burden than those living in the West.

Although climatic conditions are often associated with housing characteristics (eg, building codes and types differ by climate zones/regions), individual allergen levels, but not allergen burden, showed variation by climatic conditions. Increased dust mite allergen levels showed species-specific differences that most

likely relate to biologic and ecologic differences (eg, relative humidity and temperature requirements for reproduction and survival) between species⁴⁹; increased Der p 1 levels were most prevalent in hot humid regions, whereas increased Der f 1 levels were most frequently detected in mixed-humid/marine climates. Nonetheless, climate region remained as an independent predictor only for increased Der f 1 levels.

Allergen burden and levels of pet and dust mite allergens varied significantly across levels of urbanization in NHANES 2005-2006, whereas geographic variation was less notable in NSLAH,³³ reflecting perhaps a smaller sample size (831 households) and/or differences in urban-rural and exposure classification schemes. Allergen exposures exhibited opposite patterns compared with allergic sensitization, which was found to be more common in urban areas.¹⁸ Living in the most rural areas increased the odds of having high allergen burden (≥ 3 allergens exceeding increased levels) by more than 3-fold compared with living in a highly urbanized area. Although the odds of having increased cat and dust mite levels were significantly increased in rural homes, increased dog allergen levels were much less frequently detected in rural homes than in more urbanized areas, suggesting that dogs might be kept outdoors rather than indoors in less urbanized areas. Level of urbanization can influence environmental exposures, not only contributing to diversity and levels of microbial, pollen, and/or air pollution exposures⁵⁰⁻⁵² but also affecting characteristics of indoor allergen exposures.

Housing characteristics, which are closely associated with sociodemographic and environmental factors, had a notable influence on individual allergen levels and allergen burdens. Of the allergens, Der p 1 levels were most frequently associated with housing-related factors, especially with those reflecting lower SES and increased humidity/excess moisture in the home. Compared with NSLAH, NHANES 2005-2006 provided less detailed information on housing characteristics because it was not designed to survey housing conditions. However, both studies showed that increased allergen exposures in the home were associated consistently with housing type and the presence of pets and pests.

The national representativeness is one of the greatest strengths of NHANES 2005-2006; however, the cross-sectional design is a limitation. Although using concentrations in reservoir dust as surrogates of exposures might not be an optimal method for exposure assessment, it is an accepted and widely used method in large epidemiologic studies.^{10,53,54} Indeed, combined dust samples collected from the participant's bed and bedroom floor might be less influenced by temporal and spatial variability, more reproducible, and represent long-term exposure better than short-term air sampling. Even though repeated measurements might have improved the accuracy of exposure estimates, the within-home variance of exposures tends to be smaller than the between-home variance.⁵⁵ We acknowledge that exposures could be assessed more accurately with personal monitors because personal exposure to allergens varies in intensity, content, and particle size over time.⁵⁶ Although new and improved exposure assessment techniques can provide novel insight into the role of allergens and other environmental exposures in patients with asthma and allergies,⁵⁷ studies, especially large-scale ones, showing significant advantages for personal sampling over reservoir dust analysis are still scant.⁵⁸ Assessment of allergen burden is complicated, not only because

it is unknown whether each allergen imposes an equivalent risk but also because of residential exposure variability.⁴⁷ Our outcomes, which were based on measurements of 8 common indoor allergens, might have limited ability to reflect total allergen burden in the home. Because of the NHANES survey design, seasonal and regional variables were interrelated,⁵⁹ which made assessment of potential seasonal effects difficult. Thus caution is warranted when interpreting regional differences (eg, the survey did not account for seasonal variability in indoor temperature and humidity levels). Furthermore, methodological differences between NHANES 2005-2006 and NSLAH precluded assessment of temporal trends in allergen exposures. However, despite all limitations, NHANES 2005-2006 not only extends the knowledge on geographic and climatic variation of indoor allergens but also provides information on variability of residential allergen burden and complements the previously published sensitization findings,¹⁸ enabling comparisons between exposure and sensitization patterns in the general US population.

This comprehensive report on indoor allergen exposures highlights factors that influence allergen levels and burden in US homes. Although exposure variability showed significant racial/ethnic and regional differences, high exposure burden to multiple allergens was consistently found in homes with pets and pests, mobile homes and/or trailers, older and rental homes, and nonmetropolitan areas. Removing pets and pests from the home might not always be easy, but national data suggest that the presence of pets and pests can make a significant difference in residential allergen burden. Low allergen burden, which was rather uncommon, was associated with several additional sociodemographic and housing-related factors. In comparison with the previously published data on allergen-specific sensitization in NHANES 2005-2006,¹⁸ exposure patterns showed notable differences by sociodemographic factors (eg, sex, race/ethnicity, and level of urbanization). Further studies, preferably of longitudinal design, are needed to elucidate how genetic, socioeconomic, cultural, environmental, or other factors contribute to the complex relationships between allergen exposures and development of allergic diseases, such as asthma.

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Clinical implications: In the general US population, exposure to indoor allergens varies based on sociodemographic and housing characteristics; however, exposure patterns show sociodemographic differences when compared with sensitization patterns.

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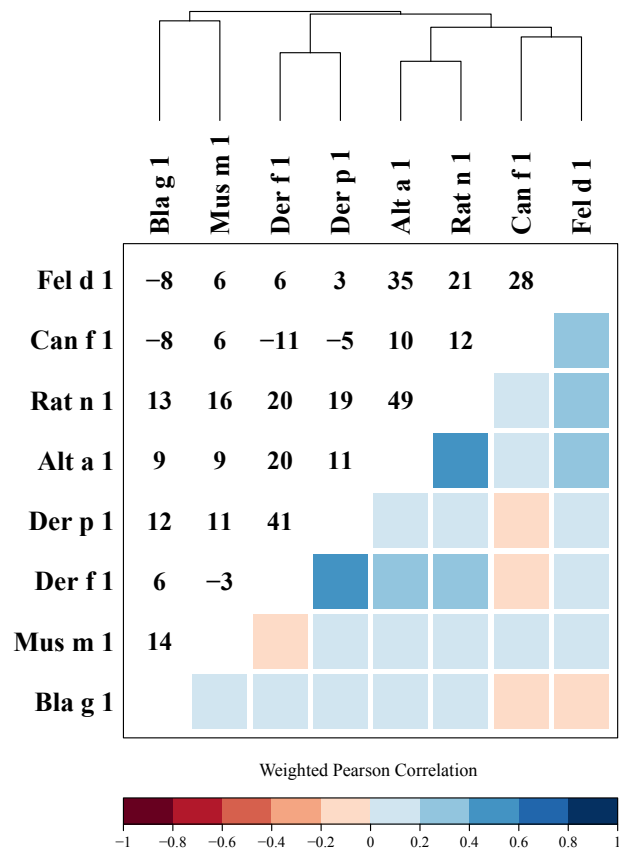


FIG E1. Clustering of allergens in NHANES 2005-2006. The dendrogram (*top*) uses hierarchical clustering to group similar allergens based on the log-transformed correlation matrix (*below*).

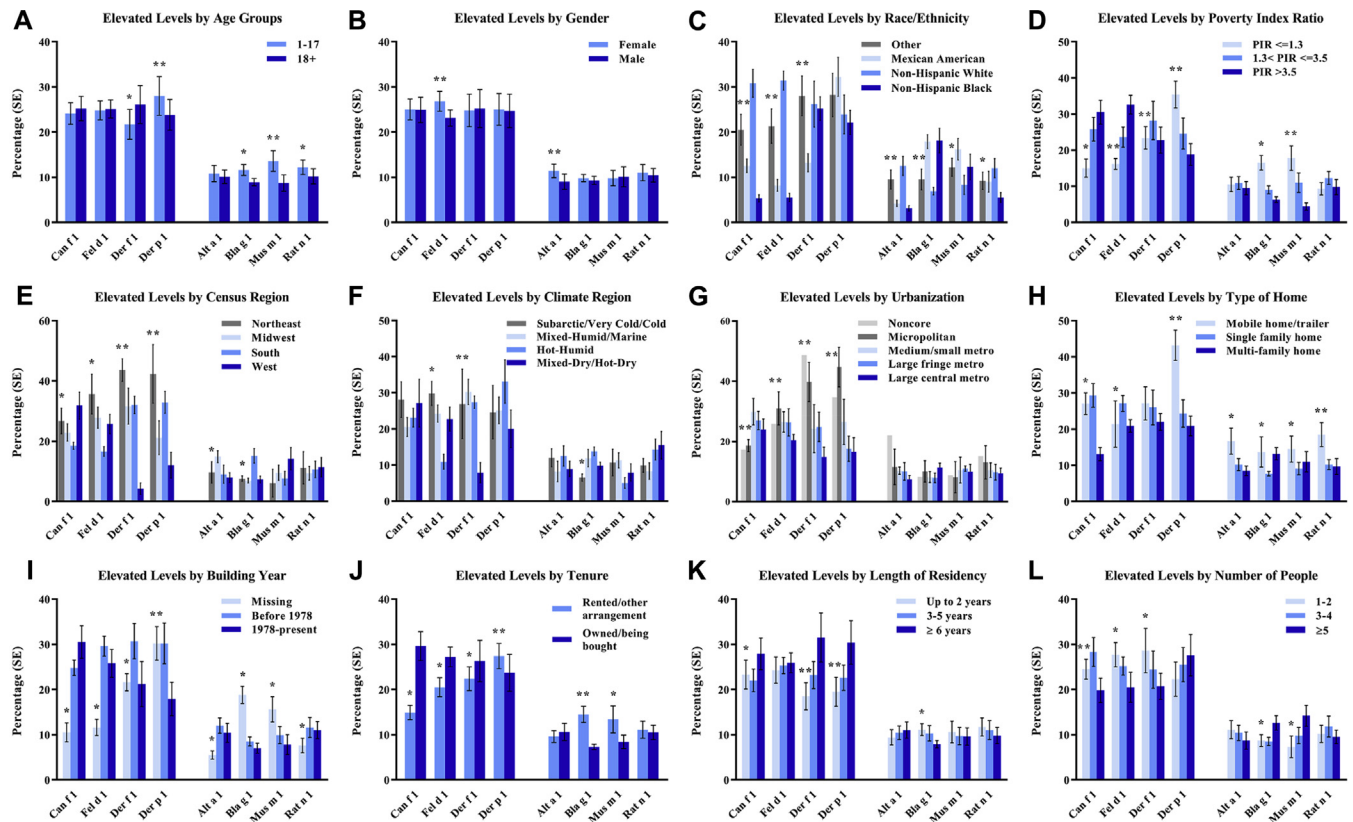


FIG E2. A-W. Prevalence of increased allergen concentrations in NHANES 2005-2006 by participant and housing characteristics. Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. Asterisks indicate whether the variable was included in predictor modeling based on the relationship observed in bivariate analyses (* $P < .25$) and remained an independent predictor in the final model (** $P < .05$). The Wald statistic was used to test differences across levels of the characteristic. The reference group in each bar graph group is shown in dark blue (ie, the *rightmost* bar).

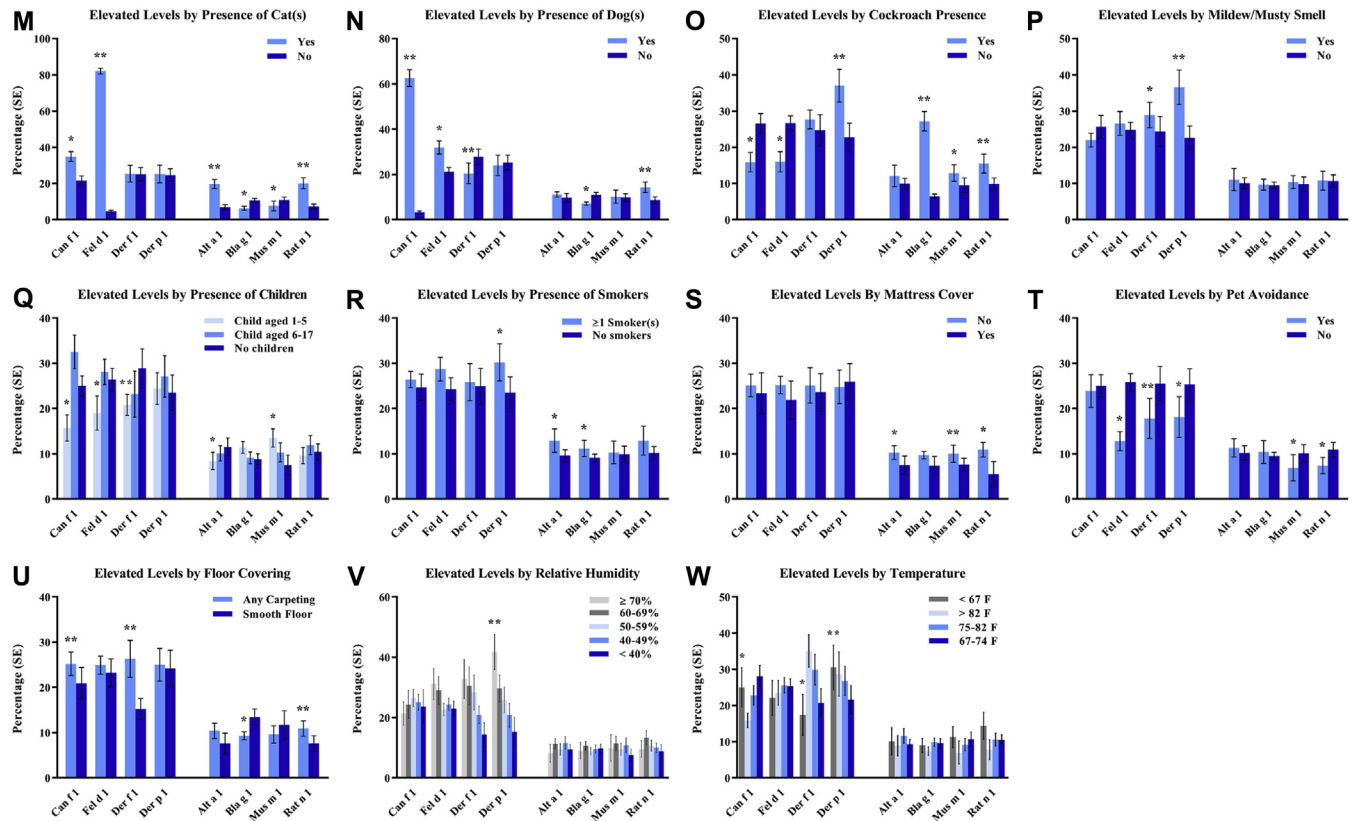


FIG E2. (Continued).

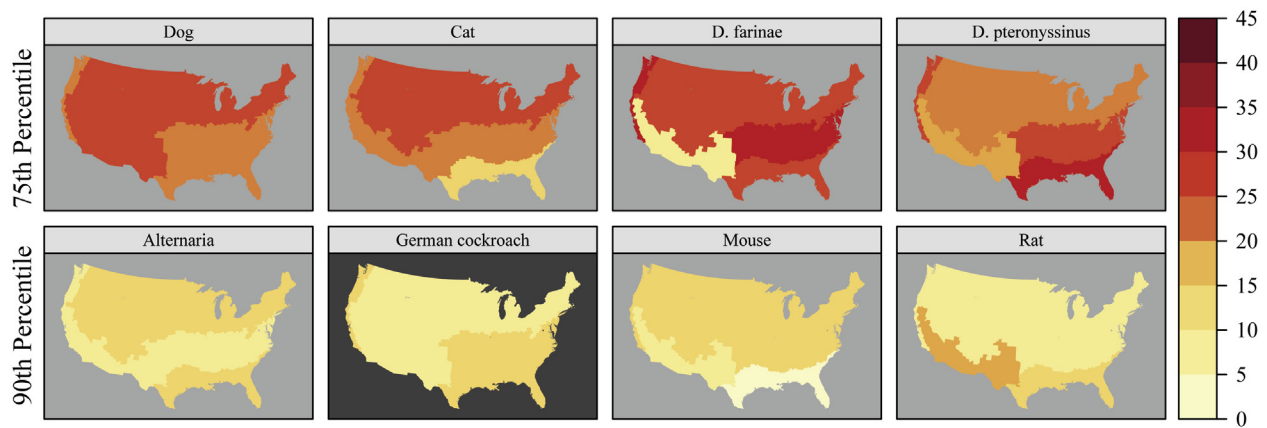


FIG E3. Prevalence of increased allergen levels by climate region. Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. The dark background color in the map indicates statistically significant differences ($P < .05$) across 4 climate regions in the United States (subarctic/very cold/cold, mixed-humid/marine, hot-humid, and mixed-dry/hot dry).

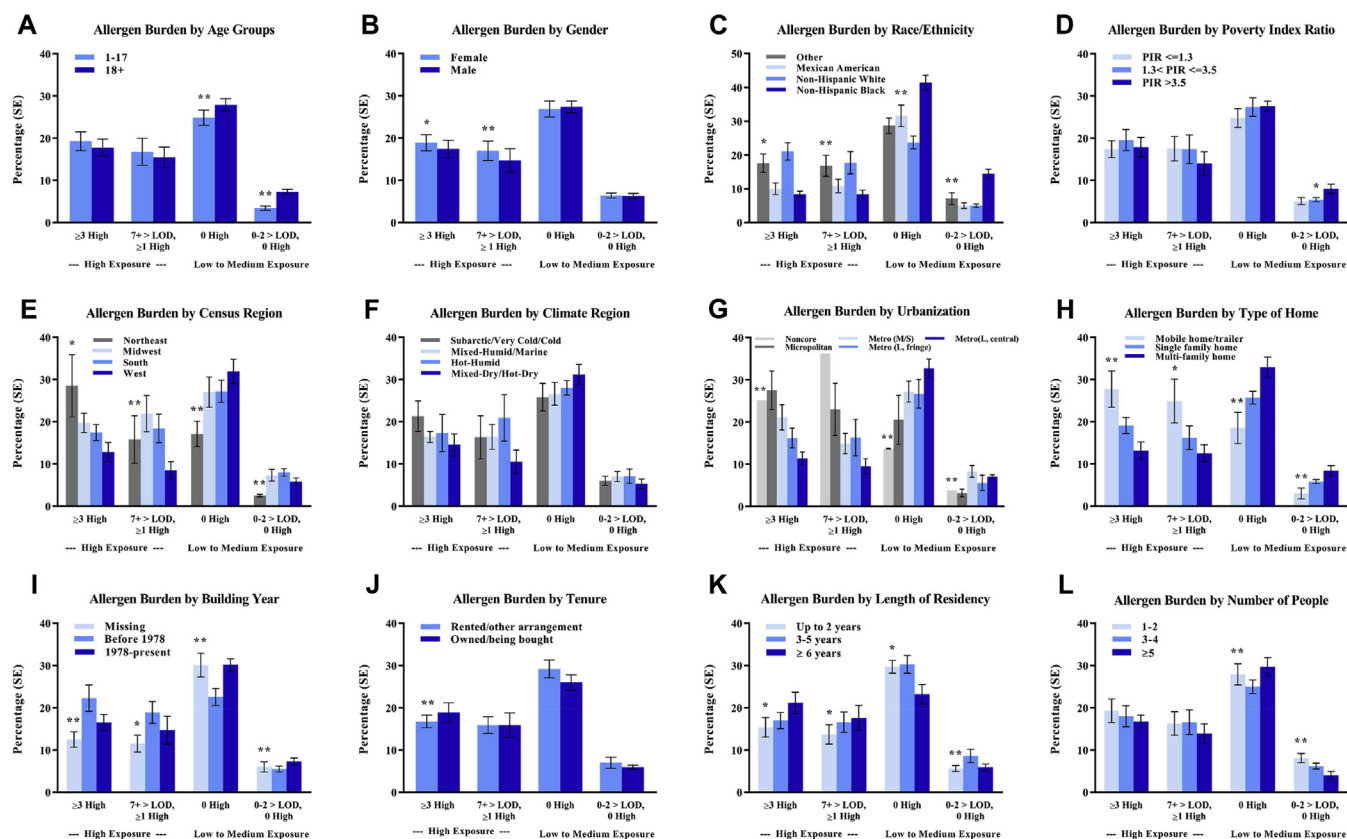


FIG E4. A-W, Prevalence of allergen burden in NHANES 2005-2006 by participant and housing characteristics. Exposure burden was classified as high when (1) ≥ 3 allergens exceeded increased levels (Can f 1, Fel d 1, Der f 1, or Der p 1 concentrations >75 th percentile; Alt a 1, Bla g 1, Mus m 1, or Rat n 1 concentrations >90 th percentile) or (2) ≥ 7 allergens exceeded limits of detection ($>LOD$) and ≥ 1 allergens exceeded increased levels. Exposure burden was low to medium when none of the allergens exceeded increased levels (irrespective of how many allergens were detected) and low when ≤ 2 allergens were detected and none of the allergens exceeded increased levels. Asterisks indicate whether the variable was included in predictor modeling ($*P < .25$) and remained an independent predictor in the final model ($**P < .05$). The Wald statistic was used to test differences across levels of the characteristic. The reference group in each bar graph group is shown in dark blue (ie, the *rightmost* bar).

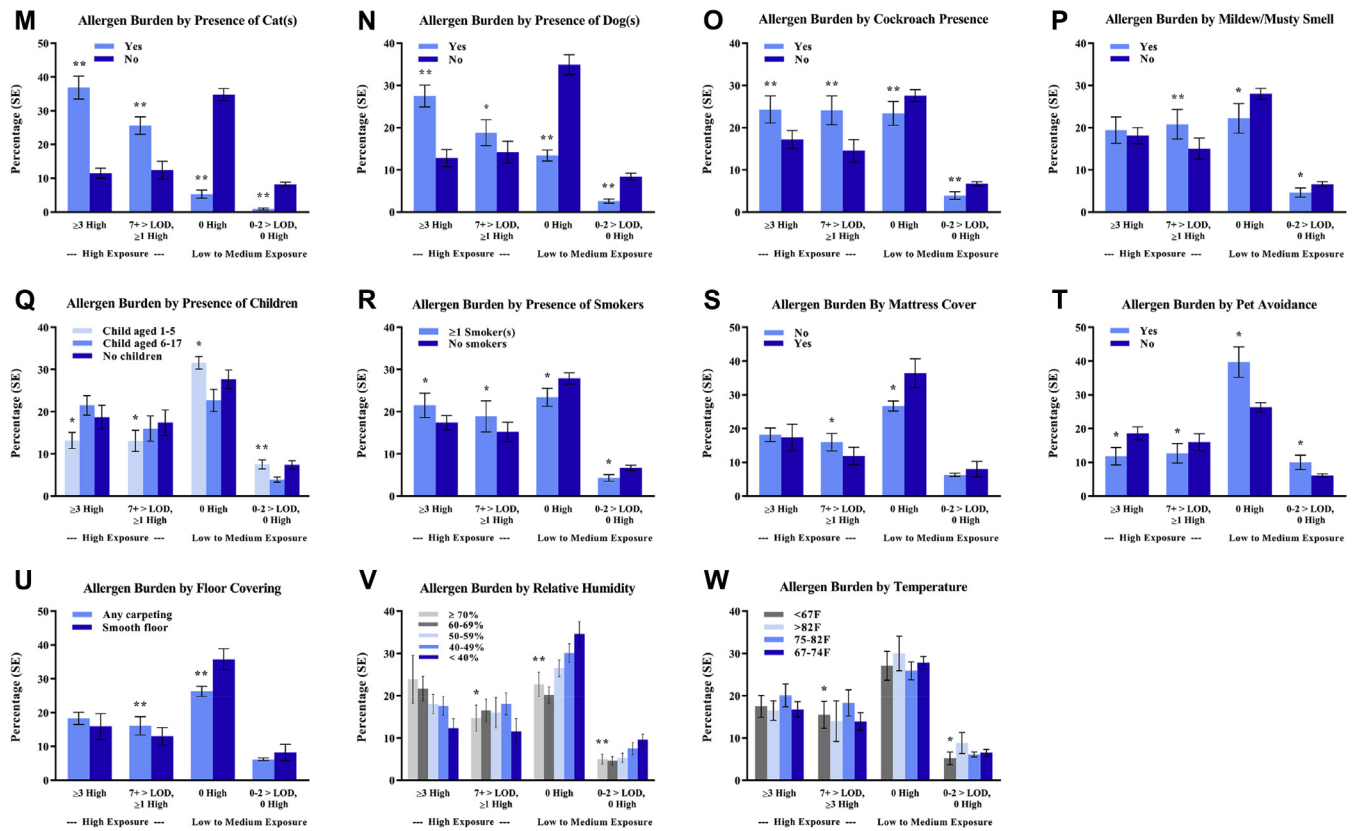


FIG E4. (Continued).

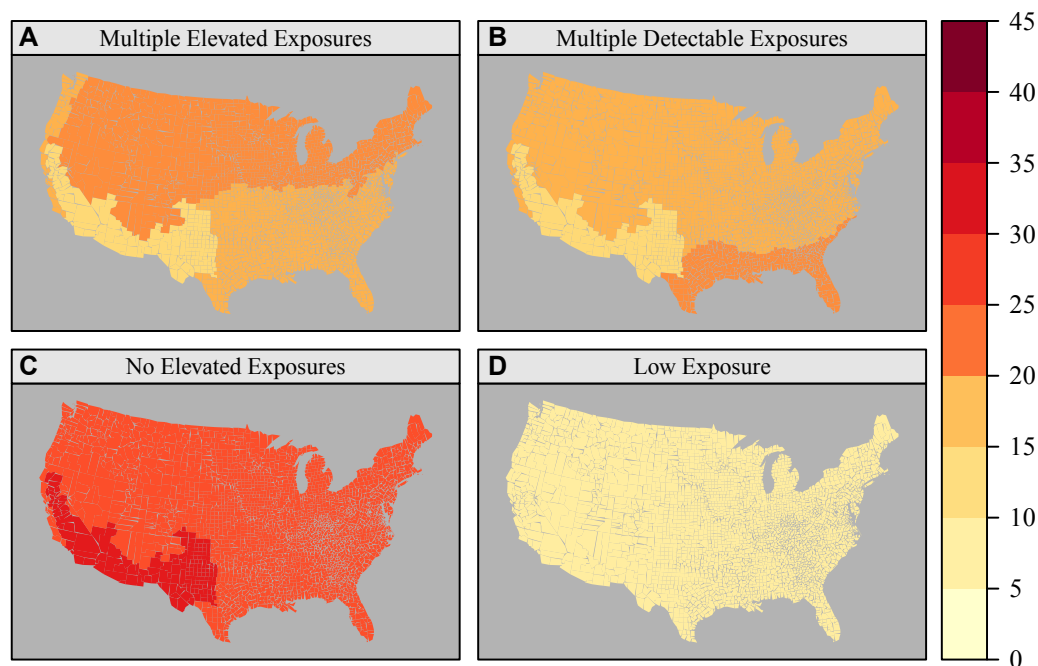


FIG E5. Prevalence of allergen burden by 4 climate regions in the United States (subarctic/very cold/cold, mixed-humid/marine, hot-humid, and mixed-dry/hot dry). Allergen burden outcomes: *Multiple Elevated Exposures* (≥ 3 allergens at increased levels) (**A**); *Multiple Detectable Exposures* (≥ 7 allergens > limit of detection, ≥ 1 allergens at increased levels) (**B**); *No Elevated Exposures* (0 allergens at increased levels) (**C**); and *Low Exposure* (≤ 2 allergens > limit of detection, 0 allergens at increased levels) (**D**). Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile.

TABLE E1. Population characteristics of NHANES 2005-2006*

Demographic characteristics	Weighted % (SE) [†]
Participant age (y)	
1-17	24.3 (0.7)
≥18	75.7 (0.7)
Sex	
Female	51.1 (0.6)
Male	48.9 (0.6)
Race/ethnicity	
Other	10.1 (1.2)
Mexican American	9.4 (1.2)
Non-Hispanic white	68.1 (2.7)
Non-Hispanic black	12.3 (1.9)
Family PIR	
Low (PIR ≤ 1.3)	22.0 (1.5)
Medium (1.3 < PIR ≤ 3.5)	40.7 (1.3)
High (PIR > 3.5)	37.3 (2.4)
Census region	
Northeast	14.5 (3.2)
Midwest	25.3 (7.3)
South	29.2 (3.4)
West	31.0 (7.6)
Level of urbanization [‡]	
Noncore	6.5 (6.5)
Micropolitan	14.9 (6.1)
Medium + small metro	27.9 (10.2)
Large metro, fringe	16.4 (8.1)
Large metro, central	34.4 (7.1)

*Participants with available dust data (n = 6963).

[†]Weighted for the multistage sampling design of NHANES.

[‡]Metropolitan counties are subdivided based on the population of their metropolitan statistical area (MSA): large (central, fringe) for an MSA population of 1 million or more, medium for an MSA population of 250,000 to 999,999, and small for an MSA population of less than 250,000. Nonmetropolitan counties not defined as micropolitan are considered to be noncore and are thought of as the most rural areas.

TABLE E2. Distributional characteristics of detectable allergen concentrations ($\mu\text{g/g}$) in NHANES 2005-2006

Allergen	No.	$\geq\text{LLOD}$ (%)	Minimum	P25	P50	P75	P90	Maximum	Geometric mean
Can f 1	5486	86.7	0.013	0.106	0.842	12.937	50.216	1216.406	1.130
Fel d 1	6106	93.0	0.004	0.063	0.344	9.238	112.500	2944.677	0.775
Der f 1	3911	58.2	0.013	0.047	0.210	1.116	3.671	141.466	0.258
Der p 1	3655	48.9	0.013	0.045	0.226	1.309	4.963	144.801	0.284
Alt a 1	1477	25.5	0.004	0.005	0.007	0.013	0.019	0.258	0.009
Bla g 1*	2527	33.3	0.220	0.628	1.135	1.960	3.964	272.440	1.426
Mus m 1	5772	80.9	0.002	0.008	0.023	0.080	0.299	134.387	0.029
Rat n 1	1897	30.3	0.004	0.006	0.009	0.015	0.023	83.867	0.011

P25, 25th percentile; P50, 50th percentile; P75, 75th percentile; P90, 90th percentile.

*Unit of measurement is units per gram.

TABLE E3. Odds ratios with 95% CIs for bivariate associations between increased allergen levels (NHANES 2005-2006)*

	Alt a 1, OR (95% CI)	Bla g 1, OR (95% CI)	Can f 1, OR (95% CI)	Der f 1, OR (95% CI)	Der p 1, OR (95% CI)	Fel d 1, OR (95% CI)	Mus m 1, OR (95% CI)	Rat n 1, OR (95% CI)
Alt a 1	NA	1.68 (1.00-2.84)	1.39 (1.06-1.82)	1.51 (1.13-2.01)	1.48 (1.00-2.18)	4.34 (3.32-5.68)	0.55 (0.33-0.92)	35.7 (19.1-66.5)
Bla g 1		NA	0.67 (0.52-0.87)	0.97 (0.69-1.37)	1.84 (1.33-2.55)	0.53 (0.37-0.77)	1.89 (1.18-3.01)	1.58 (1.09-2.31)
Can f 1			NA	0.66 (0.48-0.90)	0.87 (0.63-1.19)	2.04 (1.60-2.61)	0.81 (0.40-1.64)	1.83 (1.19-2.81)
Der f 1				NA	3.72 (2.57-5.37)	1.02 (0.81-1.29)	0.70 (0.45-1.11)	1.67 (1.16-2.41)
Der p 1					NA	1.06 (0.78-1.45)	1.22 (0.73-2.04)	1.68 (1.20-2.35)
Fel d 1						NA	0.71 (0.44-1.13)	4.16 (3.00-5.77)
Mus m 1							NA	1.14 (0.73-1.80)
Rat n 1								NA

Statistically significant associations ($P < .05$) are shown in boldface.

NA, Not applicable; OR, odds ratio.

*Allergen levels were dichotomized (increased levels: yes vs no) to calculate unadjusted odds ratios. Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile.

TABLE E4. Adjusted odds ratios for independent predictors of increased allergen levels*

Model predictors: Demographic and housing characteristics	Can f 1 (n = 6613)	P value	Fel d 1 (n = 6526)	P value	Der f 1 (n = 6369)	P value	Der p 1 (n = 6504)	P value
	OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)	
Participant age (y)								.002
1-17							1.28 (1.09-1.49)	
≥18							1.00 (reference)	
Sex				.002				
Female			1.37 (1.13-1.66)					
Male			1.00 (reference)					
Race/ethnicity		<.001		<.001		.002		
Other	2.38 (1.28-4.44)		2.25 (1.16-4.37)		2.36 (1.45-3.82)			
Mexican American	2.08 (1.16-3.74)		1.99 (1.13-3.50)		1.30 (0.81-2.10)			
Non-Hispanic white	4.31 (2.72-6.83)		3.15 (2.16-4.61)		1.29 (0.98-1.69)			
Non-Hispanic black	1.00 (reference)		1.00 (reference)		1.00 (reference)			
Family PIR				<.001		<.001		.003
Low (PIR ≤ 1.3)			0.60 (0.44-0.81)		1.16 (0.86-1.58)		1.67 (1.07-2.61)	
Medium (1.3 < PIR ≤ 3.5)			0.51 (0.40-0.64)		1.46 (1.09-1.97)		1.17 (0.84-1.64)	
High (PIR > 3.5)			1.00 (reference)		1.00 (reference)		1.00 (reference)	
Census region						<.001		.013
Northeast					17.41 (6.17-49.16)		3.93 (1.16-13.39)	
Midwest					7.68 (2.70-21.88)		1.45 (0.63-3.32)	
South					10.58 (3.82-29.31)		2.95 (1.26-6.89)	
West					1.00 (reference)		1.00 (reference)	
Level of urbanization†		<.001		<.001		<.001		<.001
Noncore	0.29 (0.21-0.40)		2.03 (1.40-2.95)		2.73 (1.77-4.23)		3.81 (1.83-7.95)	
Micropolitan	0.50 (0.32-0.78)		1.05 (0.48-2.28)		1.26 (0.76-2.11)		2.09 (0.94-4.66)	
Medium and small metropolitan	0.98 (0.65-1.48)		1.13 (0.64-1.98)		1.34 (0.84-2.13)		2.00 (0.93-4.27)	
Large metropolitan, fringe	0.94 (0.67-1.34)		1.24 (0.87-1.75)		0.86 (0.56-1.32)		0.98 (0.48-2.00)	
Large metropolitan, central	1.00 (reference)		1.00 (reference)		1.00 (reference)		1.00 (reference)	
Type of home								<.001
Mobile home or trailer							2.93 (1.85-4.64)	
Single family, detached							1.59 (1.18-2.13)	
Multifamily housing							1.00 (reference)	
Building year								<.001
Missing							2.04 (1.45-2.86)	
Before 1978							1.86 (1.31-2.63)	
1978-present							1.00 (reference)	
Tenure								.002
Rented or other arrangement							1.88 (1.25-2.82)	
Owned or being bought							1.00 (reference)	
Residence time						<.001		<.001
Up to 2 y					0.57 (0.45-0.73)		0.40 (0.28-0.58)	
3-5 y					0.66 (0.42-1.03)		0.56 (0.39-0.81)	
≥6 y					1.00 (reference)		1.00 (reference)	
No. of persons in household		<.001						
1-2	3.17 (2.09-4.80)							
3-4	2.24 (1.48-3.39)							
≥5	1.00 (reference)							
Presence of cat(s)				<.001				
Yes			94.34 (66.29-134.27)					
No			1.00 (reference)					
Presence of dog(s)		<.001				<.001		
Yes	59.28 (40.23-87.36)				0.68 (0.57-0.80)			
No	1.00 (reference)				1.00 (reference)			
Presence of cockroaches								.023
Yes							1.53 (1.06-2.20)	
No							1.00 (reference)	
Presence of mildew/musty smell								.012
Yes							1.52 (1.10-2.10)	
No							1.00 (reference)	
Presence of children						.035		
Child aged 1-5 y					0.72 (0.55-0.93)			
Child aged 6-17 y					0.78 (0.55-1.09)			
No children					1.00 (reference)			

(Continued)

TABLE E4. (Continued)

Model predictors: Demographic and housing characteristics	Can f 1 (n = 6613)	P value	Fel d 1 (n = 6526)	P value	Der f 1 (n = 6369)	P value	Der p 1 (n = 6504)	P value
	OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)	
Removal/avoidance of pets						.009		
Yes					0.63 (0.45-0.89)			
No					1.00 (reference)			
Floor covering		.032				<.001		
Carpeting or rug	1.77 (1.05-2.98)				2.49 (1.84-3.39)			
Smooth floor	1.00 (reference)				1.00 (reference)			
Room humidity								.003
≥70%							2.03 (1.19-3.46)	
60% to 69%							1.48 (0.87-2.52)	
50% to 59%							1.41 (0.94-2.11)	
40% to 49%							1.03 (0.57-1.87)	
<40%							1.00 (reference)	
Room temperature								.009
>82°F							0.97 (0.44-2.12)	
75°F-82°F							1.07 (0.79-1.45)	
<67°F							1.98 (1.28-3.05)	
67°F-74°F							1.00 (reference)	
Model predictors: demographic and housing characteristics	Alt a 1 (n = 6770)	P value	Bla g 1 (n = 6768)	P value	Mus m 1 (n = 6496)	P value	Rat n 1 (n = 6612)	P value
	OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)	
Participant's age (y)						.002		
1-17					1.44 (1.14-1.82)			
≥18					1.00 (reference)			
Sex		.047						
Female	1.27 (1.00-1.62)							
Male	1.00 (reference)							
Race/ethnicity		<.001		<.001				
Other	2.61 (1.28-5.33)		0.60 (0.32-1.13)					
Mexican American	1.37 (0.91-2.04)		0.87 (0.63-1.19)					
Non-Hispanic white	3.26 (2.11-5.02)		0.51 (0.37-0.71)					
Non-Hispanic black	1.00 (reference)		1.00 (reference)					
Family PIR						<.001		
Low (PIR ≤ 1.3)					4.64 (2.82-7.64)			
Medium (1.3 < PIR ≤ 3.5)					2.75 (1.67-4.53)			
High (PIR > 3.5)					1.00 (reference)			
Type of home								.004
Mobile home or trailer							1.72 (0.87-3.43)	
Single family, detached							0.86 (0.56-1.33)	
Multifamily housing							1.00 (reference)	
Tenure				<.001				
Rented or other arrangement			1.57 (1.22-2.02)					
Owned or being bought			1.00 (reference)					
Presence of cat(s)		<.001						<.001
Yes	2.79 (2.04-3.82)						3.18 (2.15-4.70)	
No	1.00 (reference)						1.00 (reference)	
Presence of dog(s)								.011
Yes							1.61 (1.12-2.33)	
No							1.00 (reference)	
Presence of cockroaches				<.001				<.001
Yes			4.31 (3.03-6.14)				2.03 (1.34-3.07)	
No			1.00 (ref)				1.00 (ref)	
Presence of mattress cover						.046		
No					1.48 (1.01-2.18)			
Yes					1.00 (reference)			
Floor covering								.033
Carpeting or rug							1.68 (1.04-2.70)	
Smooth floor							1.00 (reference)	

OR, Odds ratio.

*Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. The Wald statistic was used to test the significance of each variable in the model (*P* value). All odds ratios are adjusted for each variable in the final prediction model.

†Metropolitan counties are subdivided based on the population of their metropolitan statistical area (MSA): large (central, fringe) for an MSA population of 1 million or more, medium for an MSA population of 250,000 to 999,999, and small for an MSA population of less than 250,000. Nonmetropolitan counties not defined as micropolitan are considered to be noncore and are thought of as the most rural areas.

TABLE E5. Adjusted odds ratios for independent predictors of allergen burden*

Model predictors: Demographic and housing characteristics	Multiple elevated exposures (n = 6768)	P	Multiple detectable exposures (n = 6597)	P	No Elevated exposures (n = 6597)	P	Low exposure (n = 6761)	P
	OR (95% CI)	value	OR (95% CI)	value	OR (95% CI)	value	OR (95% CI)	value
Participant age (y)						<.001		<.001
1-17					0.76 (0.65-0.88)		0.43 (0.34-0.54)	
≥18					1.00 (reference)		1.00 (reference)	
Sex				.030				
Female			1.19 (1.02-1.40)					
Male			1.00 (reference)					
Race/ethnicity				<.001		.007		<.001
Other			2.61 (1.51-4.53)		0.62 (0.43-0.90)		0.50 (0.28-0.86)	
Mexican American			1.83 (1.30-2.58)		0.55 (0.39-0.77)		0.42 (0.25-0.71)	
Non-Hispanic white			2.48 (1.73-3.55)		0.63 (0.43-0.91)		0.34 (0.26-0.44)	
Non-Hispanic black			1.00 (reference)		1.00 (reference)		1.00 (reference)	
Census region				.008		<.001		.018
Northeast			1.72 (0.66-4.47)		0.60 (0.34-1.08)		0.75 (0.32-1.78)	
Midwest			3.07 (1.57-6.01)		1.01 (0.76-1.35)		1.67 (1.05-2.65)	
South			2.49 (1.21-5.14)		0.59 (0.44-0.78)		1.50 (0.92-2.44)	
West			1.00 (reference)		1.00 (reference)		1.00 (reference)	
Level of urbanization†		<.001				<.001		<.001
Noncore	3.25 (2.16-4.90)				0.26 (0.19-0.36)		0.49 (0.37-0.65)	
Micropolitan	2.78 (1.67-4.61)				0.83 (0.44-1.58)		0.46 (0.31-0.67)	
Medium and small metropolitan	2.17 (1.36-3.45)				0.88 (0.72-1.08)		1.41 (1.03-1.91)	
Large metropolitan, fringe	1.52 (1.01-2.27)				0.83 (0.59-1.17)		0.82 (0.54-1.25)	
Large metropolitan, central	1.00 (reference)				1.00 (reference)		1.00 (reference)	
Type of home		.031				.031		.011
Mobile home or trailer	1.86 (1.17-2.97)				0.63 (0.38-1.05)		0.38 (0.21-0.72)	
Single family, detached	1.21 (0.84-1.75)				0.98 (0.69-1.40)		0.86 (0.58-1.28)	
Multifamily housing	1.00 (reference)				1.00 (reference)		1.00 (reference)	
Building year		.006				<.001		.001
Missing	1.06 (0.73-1.52)				0.46 (0.32-0.67)		0.41 (0.25-0.67)	
Before 1978	1.76 (1.23-2.52)				0.53 (0.43-0.67)		0.71 (0.49-1.04)	
1978-present	1.00 (reference)				1.00 (reference)		1.00 (reference)	
Tenure		.042						
Rented or other arrangement	1.37 (1.01-1.84)							
Owned or being bought	1.00 (reference)							
Residence time								<.001
Up to 2 y							0.69 (0.45-1.05)	
3-5 y							1.21 (0.70-2.09)	
≥6 y							1.00 (reference)	
No. of persons in household						.050		.048
1-2					0.70 (0.53-0.93)		2.22 (1.16-4.27)	
3-4					0.72 (0.50-1.04)		1.48 (0.70-3.16)	
≥5					1.00 (reference)		1.00 (reference)	
Presence of cat(s)		<.001		<.001		<.001		<.001
Yes	4.25 (3.31-5.46)		2.36 (1.71-3.25)		0.10 (0.06-0.16)		0.13 (0.07-0.22)	
No	1.00 (reference)		1.00 (reference)		1.00 (reference)		1.00 (reference)	
Presence of dog(s)		<.001				<.001		.003
Yes	2.33 (1.67-3.26)				0.27 (0.18-0.42)		0.41 (0.23-0.74)	
No	1.00 (reference)				1.00 (reference)		1.00 (reference)	
Presence of cockroaches		<.001		<.001		.006		.002
Yes	2.57 (1.87-3.53)		2.14 (1.77-2.59)		0.63 (0.45-0.88)		0.41 (0.23-0.73)	
No	1.00 (reference)		1.00 (reference)		1.00 (reference)		1.00 (reference)	
Presence of mildew/musty smell				.021				
Yes			1.43 (1.05-1.93)					
No			1.00 (reference)					
Presence of children								<.001
Child aged 1-5 y							2.02 (1.22-3.34)	
Child aged 6-17 y							0.94 (0.56-1.56)	
No children							1.00 (reference)	
Floor covering				.040		<.001		
Carpeting or rug			1.47 (1.02-2.14)		0.43 (0.28-0.68)			
Smooth floor			1.00 (reference)		1.00 (reference)			

(Continued)

TABLE E5. (Continued)

Model predictors: Demographic and housing characteristics	Multiple elevated exposures (n = 6768)	P	Multiple detectable exposures (n = 6597)	P	No Elevated exposures (n = 6597)	P	Low exposure (n = 6761)	P
	OR (95% CI)	value	OR (95% CI)	value	OR (95% CI)	value	OR (95% CI)	value
Room humidity						<.001		.003
≥70%					0.68 (0.46-0.99)		0.63 (0.32-1.25)	
60% to 69%					0.50 (0.38-0.67)		0.43 (0.26-0.70)	
50% to 59%					0.65 (0.52-0.82)		0.39 (0.20-0.75)	
40% to 49%					0.88 (0.65-1.19)		0.65 (0.35-1.23)	
<40%					1.00 (reference)		1.00 (reference)	

*Allergen burden outcomes: Multiple Elevated Exposures (≥ 3 allergens at increased levels) and Multiple Detectable Exposures (≥ 7 allergens > limit of detection, ≥ 1 allergens at increased levels) represent high allergen burden. No Elevated Exposures (0 allergens at increased levels) and Low Exposure (≤ 2 allergens > limit of detection, 0 allergens at increased levels) represent low to medium allergen burden. Can f 1, Fel d 1, Der f 1, and Der p 1 levels were increased if the allergen concentration was greater than the 75th percentile; Alt a 1, Bla g 1, Mus m 1, and Rat n 1 levels were increased if the allergen concentration was greater than the 90th percentile. The Wald statistic was used to test the significance of each variable in the model (*P* value). All odds ratios are adjusted for each variable in the final prediction model.

†The metropolitan counties are subdivided based on the population of their metropolitan statistical area (MSA): large (central, fringe) for an MSA population of 1 million or more, medium for an MSA population of 250,000 to 999,999, and small for an MSA population of less than 250,000. Nonmetropolitan counties not defined as micropolitan are considered to be noncore and are thought of as the most rural areas.