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Analysis of Health Effects Associated with Indoor Environmental Quality in a Sample of U.S. Office Buildings

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List of Terms and Abbreviations

BRS	building-related symptoms
CI	confidence interval
CO_2	carbon dioxide
FG	fiberglass
OR	odds ratio
PS	polyester/synthetic
SBS	sick building syndrome
VOC	volatile organic compound
VR	ventilation rate

Abstract

Episodes of nonspecific health complaints from workers in office and commercial buildings have been reported for over 30 years. Yet the factors responsible for these symptom complaints, sometimes called sick building syndrome (SBS) or building-related symptoms (BRS), have not been clearly identified. It is now clear that the publicized buildings with such complaints are only the visible part of a larger phenomenon – studies of representative U.S. office buildings show that over 40% of indoor workers experience one or more frequent work-related symptoms in their buildings (Brightman, Wallace et al. 1999). These potential adverse effects of indoor work environments are of public health importance because the population potentially exposed is large. Approximately 89 million workers in the U.S., almost 70% of the workforce, work in indoor environments (Mendell, Fisk et al. 2002). Researchers have estimated that among the 35-60 million workers experiencing one or more weekly building-related symptoms, improved indoor environmental conditions could prevent this in 8-30 million workers each year (Mendell, Fisk et al. 2002).

To learn more about risk factors for BRS, we analyzed data from the largest available study of U.S. office workers, the Building Assessment and Survey Evaluation (BASE) Study from the U.S. Environmental Protection Agency, which involved a representative sample of 100 buildings and 4,326 workers. Analyses used separate multivariate logistic regression models for seven types of BRS. Specific aims included: to describe associations between BRS and outdoor air ventilation rates (VRs), assess if symptoms are associated with indoor chemical reactions of outdoor ozone and ventilation filters, estimate relationships between BRS and indoor thermal factors, combine risk factors identified in current and prior analyses into comprehensive statistical models, assess whether personal or psychosocial factors confound/distort apparent associations of BRS with environmental risk factors, and determine if data on occurrence of BRS in the BASE study buildings can be helpful in interpreting frequency of symptom reporting in other office buildings.

Focused BASE analyses of environmental factors and BRS identified risk factors associated with increases in multiple symptoms, such as: lower VRs (even some VRs above the current target rates); higher occupant density; polyester ventilation filters (especially in buildings with moderate to high levels of outdoor ozone); warmer winter indoor temperatures (even within the winter thermal comfort range); and colder summer indoor temperatures (below the summer comfort range). When these risk factors were combined in larger comprehensive models with prior identified risk factors from the BASE data, the risk factors associated with multiple BRS in these models included poorly maintained humidification systems, less frequently cleaned cooling coils and drain pans, outdoor air intakes closer than 60 m to the ground; polyester ventilation filters (especially in buildings with moderate or higher outdoor ozone); warmer winter indoor temperatures (even within the winter thermal comfort range); non-carpeted floors or old carpets (relative to newer carpets); *more* efficient ventilation filters; and masonry external walls.

Other analyses documented 1) that psychosocial stressors among indoor workers, although strongly associated with BRS among indoor symptoms, were independent of associations between symptoms and environmental risk factors and did not explain them, and 2) that personal factors differed sufficiently among buildings, and influenced BRS strongly enough, that it was

impractical to use the BASE symptom data as a reference for interpreting symptoms in other office buildings, because adequate statistical adjustments were not possible due to small numbers of workers available in each BASE building.

One clear descriptive finding is that most U.S. office buildings were too cold in the summer, so that less air-conditioning would bring them within the thermal comfort envelope, and might also reduce symptoms, increase thermal comfort, and decrease energy use. The analytic findings from regression models identified a set of risk factors, many not previously found, associated with increases in multiple BRS in office workers. These findings strongly suggest further research to confirm and clarify adverse effects of newly identified risk factors for BRS in office workers, and may suggest proactive changes in some design, operation, or maintenance practices in office buildings.

Highlights/Significant Findings

Findings from this project relate to three questions:

1) What environmental factors are associated with increased BRS in U.S. office buildings?
2) What is the role of psychosocial stressors and other personal factors, relative to the role of environmental factors, in BRS in U.S. office workers?
3) Can the symptom data from the BASE Study be used in a consistent way to evaluate the amounts of symptoms in other U.S. office buildings?

1) Focused analyses of environmental factors for association with BRS in the BASE data identified a number of risk factors for multiple symptoms, including lower VRs (even some VRs above the current target rates) [aim 1a]; higher occupant density [aim 1a]; polyester ventilation filters, especially with moderate to high levels of outdoor ozone [aim 3]; warmer winter temperatures even within the thermal comfort zone [aim 5]; and summer temperatures colder than the summer comfort zone [aim 5]. When these risk factors were combined in larger comprehensive models that also included prior identified risk factors in the BASE data, not all of these persisted as risk factors for multiple symptoms [aim 7].

In the final comprehensive models, the set of risk factors identified somewhat persuasively (that is, by association with at least two of seven symptoms, making chance alone a less likely explanation), included two plausible moisture/mold-related risk factors in HVAC systems: poorly maintained humidification systems, and less frequently cleaned cooling coils and drain pans [aim 7]. This raises the possibility that moisture-related indoor exposures within ventilation systems, from surfaces that are designed to stay wet, exposed to a constant stream of particles, and lying directly in the path of the air supply for occupants, are more effectively disseminated to occupants and pose a systematic and detectable risk, relative to random and diverse types of moisture in other building locations.

Aside from these factors, the final comprehensive models mostly included risk factors not previously identified: outdoor air intakes closer than 60 m to the ground; polyester ventilation filters (especially in buildings with moderately high outdoor ozone); non-carpeted floors or presence of older carpet (relative to newer carpets); *more* efficient ventilation filters; warmer winter indoor temperatures; and masonry external walls. Factors identified in focused models but related to no or only one BRS in the comprehensive models included lower VRs, higher occupant density, and colder indoor summer temperatures. These may truly be less strongly associated with symptoms after adjustment for a broad mix of other risk factors, or the restricted formatting required to fit so many variables into the same models may have interfered with the sensitivity of the models.

2) Analyses related to psychosocial stressors among workers in the BASE data confirmed that these factors are strongly associated with symptoms among indoor workers, but also that these are independent of associations found between symptoms and environmental risk factors. Neither type of factor explains away the other, or is even systematically associated [aim 2a].

3) This project also explored the potential for using the BASE data as a reference for interpreting the amount of symptoms in other single office buildings, as a guide to whether unusually high

symptoms suggest a need to investigate adverse environmental conditions [aim 6]. However, we were unable to identify a feasible method to adjust such comparisons for possible effects of personal variables that may vary widely among buildings, and strongly influence symptoms, but are not amenable to preventive actions, and may produce distorted interpretations of reported symptoms.

Overall, these findings suggest potential adverse acute effects of many common features in modern commercial buildings – some expected, but many unexpected. Among other things, the findings provide the first suggestion of possible adverse effects on the health of office workers from outdoor air intakes anywhere below an 18^{th} floor height, or from widely used synthetic materials in ventilation system filters, especially in combination with even moderately high *outdoor* ozone levels. Findings also suggest possible beneficial effects of carpeted floors, if carpets are relatively new. Confirmation is of course required for all these findings, but in addition, new explanations and mechanisms will be necessary to explain any confirmed adverse affects from many these factors.

Translation of Findings

A clear descriptive finding is that U.S. office buildings are generally too cold in the summer, and less air-conditioning so as to bring them within the thermal comfort envelope may have multiple benefits of reducing symptoms, increasing thermal comfort, and decreasing energy use and financial costs. A definite analytic finding of this project is to justify focused and efficient research to confirm and elucidate the adverse effects on BRS in office workers of the risk factors identified in these analyses. This would include epidemiologic or intervention research on the associations, and surveys to characterize the current extent and magnitude of the potentially adverse conditions in the building stock.

Future investigations should assess potential benefits to health/symptoms of occupants from changes in the following factors of design, operation, or maintenance in office buildings:

- Improved design or maintenance, or the elimination, of central humidification systems
- Improved maintenance of cooling coils and condensation pans
- Higher location or inclusion of air cleaning for outdoor air intakes
- Use of non-synthetic ventilation filter materials
- Maintenance of office environments at the cooler end of the thermal comfort envelope in winter, and not below the thermal comfort envelope in summer
- Use of carpets, and replacement of older carpets
- With masonry external walls, precautions to prevent still uncharacterized problems, such as covert moisture infiltration
- Provision of ventilation rates somewhat higher than current target levels

Outcomes/Relevance/Impact

A definite analytic finding of this project is to justify focused and efficient research to confirm and elucidate the adverse effects on BRS in office workers of the risk factors identified in these analyses. This would include epidemiologic or intervention research on the associations, and surveys to characterize the current extent and magnitude of the potentially adverse conditions in the building stock. A clear descriptive finding is that U.S. office buildings are generally too cold in the summer, and less air-conditioning so as to bring them within the thermal comfort envelope may have the multiple benefits of reducing symptoms, increasing thermal comfort, and decreasing energy use and financial costs.

For now, findings from the focused and comprehensive models in this project provide only initial evidence for potential health benefits from a variety of changes in the design, operation, or maintenance of modern office buildings, including:

- Improved design or maintenance, or the elimination, of central humidification systems
- Improved maintenance of cooling coils and condensation pans
- Higher location or inclusion of air cleaning for outdoor air intakes
- Use of non-synthetic ventilation filter materials
- Maintenance of office environments at the cooler end of the thermal comfort envelope in winter, and not below the thermal comfort envelope in summer
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Scientific Report

<u>Background</u>

Historically, buildings have been considered to provide controlled, safe, and healthy environments for the occupants. A variety of recent scientific evidence, however, has shown that indoor environments in buildings can produce chemical, biological, and physical exposures with irritant, toxic, allergenic, carcinogenic, or other adverse health effects. These exposures, including mold and bacteria, chemical emissions, and stressful thermal conditions, are now known to occur in offices and other indoor work environments traditionally considered free of the harmful exposures recognized to occur in industrial or agricultural workplaces (Mendell, Fisk et al. 2002). Recognized health effects from exposures in indoor work environments include building-related asthma and allergic disease and nonspecific building-related symptoms (sometimes called sick building syndrome).

The population of potentially exposed indoor workers, approximately 89 million, is large. Traditional industrial occupational exposure standards may not adequately protect these indoor workers, who, relative to industrial workers, are a more diverse and potentially susceptible population exposed to complex mixtures of many substances at low levels. Perhaps more importantly, documenting comprehensively protective exposure levels in indoor environments has not been possible, because the specific causal exposures of concern for some observed health effects have not yet been identified and measured.

Until specific health-protective indoor exposure standards can be produced, guidelines based on identified *qualitative* risk factors, such as practices of building design, operation, and maintenance, will be necessary to reduce risks from as yet uncharacterized exposures in indoor work environments One aspect of building operation, ventilation with outdoor air, is particularly critical, in that it dilutes and reduces exposures to a wide range of indoor contaminants and thus provides general protection. Yet there has been little scientific attention to documenting the effectiveness of specific practices of building design, operation, and maintenance in general, and of specific rates of ventilation in particular, in protecting the health of building occupants.

Ultimately, research needs to provide a scientific basis for health-protective guidelines and standards in indoor work environments, to be implemented through a combination of acceptability standards for indoor exposures, building practices of design, operation, and maintenance, and rates of outdoor air ventilation. This project made use of a large data set collected in U.S. office buildings for the explicit purpose of allowing research toward these goals.

Current knowledge about building-related symptoms, asthma, and allergy in offices

Symptoms such as eye, nose, or throat irritation, headache, and fatigue, potentially resulting from allergic, irritant, toxic, infectious, or other disease processes, are sometimes called nonspecific symptoms. Highly publicized episodes of buildings with widespread occupant complaints of building-related symptoms, although becoming commonplace, still are reported from a small minority of buildings. Recent studies of representative sets of U.S. office buildings, however (rather than buildings with known complaints) indicate that over 40% of workers experience frequent work-related symptoms (Fisk, Mendell et al. 1993; Nelson, Kaufman et al. 1995; Brightman, Wallace et al. 1999). Thus, the relatively few publicized buildings with such complaints are apparently only the visible part of a larger invisible, poorly understood phenomenon.

Problem-solving investigations of buildings with occupant complaints have often observed these complaints to occur *in conjunction with* deficient ventilation, moisture damage, visible microbiologic growth, or recent construction or renovation, but these practical investigations have not systematically tested these relationships. Only in the last 20 years have scientific studies begun systematically assessing environmental risk factors for symptoms in offices and other indoor workplaces. Few measured indoor exposures in offices (including specific chemicals, total volatile organic chemicals, and total concentrations of culturable airborne fungi or bacteria) have been associated in these studies with symptoms or other acute health effects in workers. Numerous building *conditions or practices* that are potential *indicators* of unmeasured indoor exposures, however, have been associated with these symptoms. Increased prevalence of symptoms or alterations in objective health measurements have been associated with common features in buildings such as air conditioning or mechanical ventilation systems, inadequacies in ventilation systems, and lower outdoor air ventilation rates (Mendell 1993; Sieber, Stayner et al. 1996; Wålinder, Norbäck et al. 1997; Wålinder, Norbäck et al. 1998; Seppanen, Fisk et al. 1999). Improvements in symptoms or in objective health measurements have been associated with experimentally improved indoor environments (Wyon 1992; Kemp, Dingle et al. 1998; Skyberg, Skulberg et al. 1999; Wargocki, Wyon et al. 1999). Building-related symptoms have also been associated with absenteeism (Preller, Zweers et al. 1990), objectively measured health effects (Franck and Skov 1991 1067; Wyon 1992) and impaired performance on work-related tests (Nunes, Menzies et al. 1993; Myhrvold, Olsen et al. 1996; Myhrvold and Olsen 1997; Wargocki, Wyon et al. 1999; Wargocki, Wyon et al. 2000; Wargocki, Wyon et al. 2000).

Promising recent research has found increases in symptom prevalence associated with exposure metrics not traditionally used indoors: microbiologic toxins such as endotoxins or ß-1,3-glucans (Teeuw, Vandenbroucke-Grauls et al. 1994; Rylander 1996), metrics for correlated clusters of volatile organic compounds (VOC) concentrations indicating recognizable sources such as paint or vehicle exhaust (Ten Brinke, Selvin et al. 1998; Apte and Daisey 1999), combinations of low-level VOCs with additive irritant effects (Cometto-Muniz and Cain 1994). Other recent work has demonstrated creation of unmeasured but highly irritant compounds through indoor chemical reactions (Weschler and Shields 2000; Wolkoff, Clausen et al. 2000).

The associations observed, plus considerations of biological plausibility, suggest a number of causes for building-related symptoms. These include exposures to allergenic or irritating aerosols (particularly bioaerosols), to volatile or semi-volatile organic compounds (VOCs or SVOCs) emitted by building materials, furnishings, office equipment, or products such as cleaning compounds or pesticides, and to irritant chemicals produced in indoor chemical reactions. Physical factors (particularly temperature), psychosocial stressors, and individual susceptibility are considered important co-factors.

Nonspecific building-related symptoms may represent subclinical or unrecognized manifestations of known diseases. Serious work-related allergic diseases such as hypersensitivity pneumonitis and asthma have been documented among office workers (Committee on the Assessment of Asthma and Indoor Air 2000; Seuri, Husman et al. 2000). Causes have included microbiologic exposures resulting from water leaks, contaminated ventilation system components, and other building inadequacies (Hodgson, Morey et al. 1987; Kreiss 1989; Hoffman, Wood et al. 1993). Work-related asthma has been shown to occur in indoor non-industrial work settings (Milton, Solomon et al. 1998). Building-related influences on allergic rhinitis and chronic sinusitis, although widely reported anecdotally, have been virtually unstudied. Overall, despite the potential for indoor environmental conditions to cause reasonably well-defined allergic respiratory diseases, specific causal exposures have not been identified, and therefore defining dose-response relations and health-protective exposure standards has been impossible.

Significance

These potential adverse effects of indoor work environments are of public health importance, whether these health effects involve asthma, allergic disease, or acute irritation with no chronic component, because the population potentially exposed is so large. Approximately 89 million workers in the U.S., almost 70% of the workforce, work in indoor environments (Mendell, Fisk et al. 2002). The National Occupational Research Agenda Team for Indoor Environments has estimated that among the 35-60 million workers experiencing one or more weekly building-related symptoms, improved indoor environmental conditions could prevent this in 8-30 million workers each year (Mendell, Fisk et al. 2002). Also, improved environments could prevent building-related asthma episodes among an estimated 0.3-0.7 million workers and building-relate allergy episodes among an estimated 1-3 million workers. These reductions in health effects would result in potential annual benefits ranging from $4-70 billion from reduced nonspecific building-related symptoms, mostly from improved work performance, and from $200 to $600 million from reduced asthma and allergies. Based on input from hundreds of organizations and individuals, the National Occupational Research Agenda has specified indoor work environments as a priority research topic for the next decade (Rosenstock, Olenec et al. 1998).

Source data – The U.S. EPA BASE Study

Substantial epidemiologic research on indoor environments has been conducted in Europe over the last decades, in both offices and homes and their effects on building-related asthma, allergy, and nonspecific symptoms. Most available scientific knowledge comes from these European research efforts. In the United States, beyond many hundreds of problem-focused investigations of buildings with occupant complaints, relatively little etiologic research on health effects of indoor environments in offices or other indoor work environments has been conducted. The exceptions include the California Healthy Buildings Study, a study of symptoms and building-related risk factors in a representative sample of office buildings in California (Mendell, Fisk et al. 1996), the NIOSH "CBS" study, an analysis of data from a set of buildings with occupant complaints investigated by NIOSH (Sieber, Stayner et al. 1996; Mendell, Naco et al. 2003), and studies of the relationships between ventilation rate and absenteeism in offices (Milton, Glencross et al. 2000).

There is a single, large, untapped resource in the U.S. for research on health effects of indoor work environments -- the Building Assessment and Survey Evaluation (BASE) Study, a survey carefully designed and conducted by the U.S. Environmental Protection Agency (EPA), involving a representative sample of office spaces containing 4,326 office workers in 100 institutional and commercial buildings across the country. The BASE data includes 42 computerized datasets: 29 datasets containing environmental measurements (e.g., multiple specific volatile organic chemicals, carbon monoxide, carbon dioxide, ventilation rates, fungi, bacteria, temperature, humidity), 10 datasets containing building characterizations (e.g., type of ventilation systems, types of building materials, interior surface materials, finishes, and furniture, operation and maintenance practices for buildings and ventilation systems, housekeeping practices and products, history and evidence of moisture incursions and damage, renovation activities, density of occupancy), and 3 datasets human questionnaire responses (e.g., history of specific medical conditions, frequency and building-relatedness of a variety of symptoms, demographic information, job information, psycho-social information, workspace information). This is the only such data available in the U.S.

This survey was designed (1) to provide baseline data on exposures, conditions, and characteristics of buildings and on building-related symptoms and perceptions of occupants, and (2) to allow, through cross-sectional analyses, generation of hypotheses about the relationships between the indoor office environments and responses among the occupants. The questionnaire and data collection protocol were designed in a multi-year process of consultation with a large multidisciplinary group of leading experts (epidemiologists, chemists, microbiologists, engineers, psychologists) through a series of workshops. The design was finalized in parallel with a survey of indoor work environments investigated for worker complaints, performed by the National Institute for Occupational Safety and Health (NIOSH). Eventually, the entire collection of final datasets will be released to the public for analysis by interested researchers. The multiple millions of dollars allocated for the BASE project funded design of the survey over several years, collection of the data over four more years, and cleaning and organization of the multiple large datasets produced, but did not fund analyses. A number of limited analyses had been performed using early versions of the dataset made available to several research groups, including the Indoor Environment Department at Lawrence Berkeley National Laboratory (IED/LBNL). The BASE data currently in use at IED/LBNL, after additional minor error corrections, will be the final version for upcoming public release. These data represented a unique, invaluable, and grossly under-used resource for performing cost-effective research into relationships between indoor environments and acute health effects among U.S. office workers.

Specific aims

(1) Original: to describe the relationships between *outdoor air ventilation rates* and symptoms among indoor workers, using improved ventilation rate estimates, in order to provide input for health-protective ventilation standards for indoor workers;
(1a) Revised: To describe the associations between building-related symptoms (BRS) and outdoor air ventilation estimated in 6 ways, using estimated values for missing personal variables, comparing associations across ventilation estimation methods, and considering the feasibility of using quantitative risk assessment approaches, in order to provide input for health-protective ventilation standards for indoor workers. (Before the NIOSH proposal was approved, an analysis similar to that of the original aim 1 but of smaller scope was funded by the U.S. Department of Energy. The remaining unfunded part of aim 1, plus additional elements, became the revised aim 1a. For details, see Appendix 1.)

(2) Original: To assess risks for symptoms among indoor workers from *sources of indoor chemical emissions*, including surface materials and cleaning products.
    (2a) Revised: To assess whether psychosocial factors in offices are risks for BRS among indoor workers and whether psychosocial factors confound associations of BRS with building-related risk factors. {Because preliminary analyses showed that the amount and quality of variables for the original analysis planned for aim 2 was inadequate, a new aim was developed. For details, see Appendix 2.)
(3) To assess evidence for irritation symptoms from products of indoor chemical reactions between reactive gases and organic compounds in indoor air or on indoor surfaces, by analyzing BASE data on symptoms and volatile organic compounds with newly obtained data on outdoor ozone concentrations, filter materials, and filter surface area;
(4) To assess evidence for effect modification by ventilation rate of the risk of irritant symptoms from chemical compounds produced by indoor pollutant sources or reactions
(5) To estimate the relationships between indoor thermal factors and BRS in indoor workers, using various metrics for temperature and humidity, and to help explain discrepancies between conventional guidelines and other research findings
(6) To calculate normative distributions of BRS prevalence among workers in U.S. office buildings, in ways that assist building managers and investigators in the interpretation of symptoms reported in specific indoor work settings
(7) To combine key risks and effect modifiers identified in focused analyses described above into comprehensive models and, based on a review and synthesis of overall findings in the BASE data with other current knowledge, to define priority issues for future research using the BASE data or requiring new research efforts

Procedures and methodology

The primary risk factors, covariates, and specific outcome measures varied for the specific multivariate analyses in this project. The primary type of statistical modeling used was logistic regression. Results were estimated as odds ratios, confidence intervals, and p-values. To correct for potential correlation among occupants of the same building resulting from factors not reflected in the logistic models, the final multivariate models were adjusted for multi-level effects using generalized estimating equations (SAS, Proc GenMod) (Liang and Zeger 1986).

The multivariate models were built using an articulated algorithm based on contribution to the model and potential confounding, after careful evaluation of the bivariate relationships between each potential risk factor and the relevant outcome measure. The models included primarily variables derived from the BASE data, but this was supplemented as needed with additional data from outside sources. All statistical modeling was done using SAS version 8.2 or later releases.

Statistical methods used in building the multivariate models involved a combination of approaches. First relevant variables were identified from among the 42 BASE datasets. Selected variables were transformed to forms appropriate for use in multivariate analysis (these included both categorical and continuous variables) and, as appropriate, combined with other variables to produce analytic datasets. Bivariate analyses of the relationship between selected independent variables (including hypothesized risk factors and known or presumed confounders) and the major outcome measures were used to select variables for inclusion in initial, focused multivariate models. Candidate variables were further evaluated in these initial multivariate models for their statistical contribution to the model as main effects and/or effect modifiers, or as confounders. Final multivariate models were constructed from those variables that were retained. In cases where two or more variables correlated strongly, index variables may be constructed to summarize the effects of such variables.

Specific analytic plans (by specific aim)

(1a) Multivariate models were constructed to describe the relationships between outdoor air ventilation rates and symptoms among indoor workers, using improved ventilation rate estimates. Those relationships were to be compared to the associations found with the original (dCO_2) ventilation rate metrics. In addition, the shape of the dose/response relationship between ventilation and symptoms was to be investigated as feasible for evidence of a threshold for effects, versus a linear effect at all levels. Lastly, different ventilation metrics were to be compared for their strength of associations with symptoms. Alternative metrics were to be assessed, to include ventilation rate per occupant, ventilation rate per area (or volume) of indoor space, and combinations of the two.

(2a) We identified available data variables in BASE on psychosocial stressors in the workplace (including job type, job satisfaction, job conflict, job demand, and job clarity). We then estimated unadjusted associations between psychosocial stressors and symptoms. We also, using multivariate risk estimation models, investigated changes in unadjusted estimates when adjusted for environmental risk factors in the BASE data, and vice versa.

(3) We obtained and included additional variables in our analysis dataset: outdoor ozone concentrations, and material and efficiency characteristics of air filters in ventilation systems for the study spaces. Multivariate analyses were used to assess whether filter characteristics or outdoor ozone were associated with symptoms, and whether these two variables modified each other's associations with symptoms.

(4) Multivariate models were used to assess the evidence for the hypothesis that ventilation rate modifies the risk for irritant symptoms from chemical compounds produced by indoor pollutant sources or indoor chemical reactions. This effect modification was expected to occur for risks related to presence of *sources* of contamination, the indoor concentration of whose emissions would be influenced by ventilation.

(5) Multivariate models were used to estimate the relationships between symptoms in indoor workers and indoor thermal factors to explain unexpected recent findings that as temperatures increase, even within the currently accepted thermal comfort envelope, symptoms and discomfort increase and performance indicators are adversely affected. Because the BASE dataset includes real-time data on temperature for a large number of buildings and workers, additional analyses used other appropriate metrics combining temperatures and time. Models adjusted as necessary for confounding by such factors as region, heating and cooling degree-days, and season. Metrics of humidity that are uncorrelated with temperature (e.g., humidity ratio) were also included in order to separately assess the effects of these two important parameters.

The following analyses performed: 1) assessment of the bivariate relationships of temperature and humidity to building-related symptoms, using a variety of metrics for temperature including time-weighted average, time above specific cut points, and degree-hours above specific cut points, and also using a metric of absolute humidity such as humidity ratio. After selection of the most sensitive metrics for temperature and humidity, multivariate logistic models were constructed, including terms for temperature, humidity, season, and other confounders and risks identified in prior analyses.

(6) Distributions of symptom prevalence were calculated and influence of non-environmental variables explored, to determine an appropriate format for summarizing symptom distribution data for use by building managers or investigators. Distributions were prepared for the study population overall, and separately by subgroups of key confounding variables, such as by gender. Data were explored to assess major non-environmental influences on symptom prevalence that may require consideration in evaluating symptoms in specific buildings. Feasible strategies for deciding acceptable levels of symptoms, versus levels requiring investigation or action, were also considered.

(7) Results of the multivariate models resulting from the analytic activities undertaken to accomplish the previous analyses were combined into comprehensive models. Risk factors initially included were identified in previous analyses of BASE data that focused closely on related groups of risk factors, including HVAC design and maintenance, ventilation, temperature and humidity, water damage, and diverse indoor contaminants. Risk factors were chosen for this analysis either because they showed associations with symptom outcomes in previous analyses or because they were of theoretical interest to a comprehensive model. Logistic regression models with generalized estimating equations were constructed with these risk factors and potential environmental and personal confounding variables. These initial models, however, contained too many variables for the available numbers of observations. This required reducing the numbers of terms in the models, which we accomplished in several ways: 1) restricting models to variables of strong a priori interest plus other factors showing strong associations with symptoms; 2) using increasingly strict statistical criteria for inclusion of independent terms in models; 3) for variables with multiple categories, either collapsing categories with similar levels of risk or replacing with single continuous terms; and 4) setting stricter criteria for inclusion of confounding variables in the models.

<u>Results and Discussion (by specific aim)</u>

(1a) *To describe the associations between building-related symptoms (BRS) and outdoor air ventilation*

We produced final models investigating the associations between seven types of occupant symptoms and six different estimators of outdoor air ventilation rate: three primary estimators in units of outdoor air flow, and three secondary estimators in units of CO2 concentration. Findings varied substantially for the first three estimators, but were similar among one of the first three and the remaining three. At least two of the primary VR estimators showed decreased prevalence of lower respiratory, upper respiratory, eye, and muscle pain symptoms with ventilation rates above 10 l/second-person; and a tendency to decrease even further at higher ventilation rates. The third primary estimator showed generally stronger associations, and associations for additional symptoms. All models showed increasing prevalence of most symptoms at even slightly higher occupant densities.

Analyses included data from the 87 air-conditioned office buildings in the BASE study that had data for three estimators of VR, all in l/s-person: VRs estimated from peak indoor minus outdoor carbon dioxide (peak delta CO_2), volumetric estimates of flow rates, and CO_2 ratio in airstreams. We also conducted analyses with three additional metrics based on CO_2 concentrations that are often used as practical *proxies for VRs*, all in parts per million (ppm) – peak delta CO_2, mean delta CO_2, and mean indoor CO_2. We used multivariate logistic regression models with generalized estimating equations to estimate the strength of associations between the three estimators of ventilation rate per person in these office buildings (and the three VR proxies) and the occurrence of building-related symptoms in the occupants, adjusted for potential confounding variables. Increased VR estimated by either peak CO_2 or volumetric flow was associated with decreased lower respiratory, upper respiratory, and eye symptoms, whereas increased VR estimated by CO_2 ratio was associated only with decreased upper respiratory symptoms. VR estimators up to *3 to 14* Ls^{-1} *per person above* the current 10 Ls^{-1} per person target levels for offices were generally associated with reduced symptom prevalence (6-48% reduced odds), but ventilation rates above these levels were not consistently associated with further reductions in symptoms. The three CO_2-based VR proxies were associated with symptoms in a way similar to, or less strong than, the delta CO_2 VR estimator, and were not explored further. For the three VR estimators, higher occupant density, even with adjustment for VR, was independently associated with increased symptoms.

VRs above current target ventilation levels thus might substantially reduce symptoms in office workers, with higher occupant densities playing an additional, unrecognized role in ventilation requirements. Because differences in findings for the various ventilation estimators were surprisingly large, development of reliable VR measurements will be necessary to clarify these relationships.

Another part of this specific aim was to consider how the estimated VR/symptom associations in the BASE data could be used in an analogy to “exposure/response” relations. The goal would be to use BASE and other data as part of a risk assessment process for ventilation rate, not as an exposure but as a controller of exposures, to support health-based minimum ventilation guidelines, analogous to health based maximum exposure guidelines. For this purpose, the estimates of VR/symptom associations from these BASE analyses were used as input for a separate meta-analysis project. This project analyzed data from BASE and other available analyses on VR/symptom associations in commercial buildings, to estimate relationships of VR to symptoms of all kinds combined, at different VRs (Fisk, Mirer et al. 2008). The conclusion was expressed relative to a commonly used current target level for VR in office buildings, 10 L/s-person. As the ventilation rates drop from 10 to 5 L/s-person, relative SBS symptom prevalence increases approximately 23% (12% to 32%), which suggests that buildings meeting the current VR target levels are providing health benefits to occupants. In addition, however, the analysis estimated that as ventilation rates *increased further* above 10 to 25 L/s-person, relative symptom prevalence decreases approximately 29% (15% to 42%). Thus VR guidelines above current VR target levels would be expected to provide further health benefits to indoor workers in the form of reduced acute symptoms.

(2a) *To assess whether psychosocial factors in offices are risks for BRS among indoor workers and whether psychosocial factors confound associations of BRS with building-related risk factors* –
Some psychosocial and some indoor environmental factors were related to symptoms in office workers. Adjustment of each factor for the other in models had little effect on the strengths of association. The two types of factor were independent risk factors for symptoms and did not confound each other in this dataset.

This lack of confounding, although not surprising, had apparently not been explicitly investigated. Findings suggest that associations of building-related symptoms with both psychosocial and environmental factors in representative buildings are not affected by mutual confounding, and that research is necessary to identify specific preventive strategies for both kinds of factor.

(3) *To assess evidence for irritation symptoms from products of indoor chemical reactions between reactive gases and organic compounds in indoor air or on indoor surfaces* –
Relative to fiberglass filters with low outdoor ozone concentrations (FG+low ozone), polyester/synthetic filters (PS) with low ozone or FG with high ozone each had significant ($p<0.05$) associations only with fatigue/difficulty concentrating (ORs = 1.93, 1.54, respectively). However, joint exposure to both PS+high ozone, relative to FG+low ozone, had significant relationships with lower and upper respiratory, cough, eye, fatigue, and headache symptoms. These ORs ranged from 2.26-5.90. Joint ORs for PS+high ozone, relative to FG+low ozone, were for lower and upper respiratory and headache BRS much greater than multiplicative, with interaction p-values < 0.10. Estimates of attributable risk proportions suggest that, assuming the associations found represented unbiased, directly causal relationships, removing both risk factors (PR and high ozone) could reduce specific building-related symptoms by approximately 26-62%.

These findings suggest possible adverse health consequences from chemical interactions between outdoor ozone and PS filters in building. Results need confirmation before recommending changes in building operation. However, if additional research confirms causality, estimates indicate that appropriate filter selection may substantially reduce BRS in buildings, especially in high ozone areas.

(4) *To assess evidence for effect modification by ventilation rate of the risk of irritant symptoms from chemical compounds produced by indoor pollutant sources or reactions*–
All exploration of potential effect modification by ventilation of the effects of indoor irritants failed to show any substantial effects. These associations were explored within individual analyses, and thus interaction terms for ventilation rate and specific irritant sources were not included in any final regression models.

(5) *To estimate the relationships between indoor thermal factors and BRS in indoor workers, using various metrics for temperature and humidity –*

Winter indoor temperatures in the study buildings spanned the recommended winter comfort range; summer temperatures were mostly *colder* than the recommended summer range. Increasing indoor temperatures, overall, were associated with increases in few symptoms. Higher winter indoor temperatures, however, were associated with increases in all symptoms analyzed. Higher summer temperatures, above 23°C, were associated with *decreases* in most symptoms. Humidity ratio, a metric of absolute humidity, showed few clear associations. Thus, increased symptoms with higher temperatures within the thermal comfort range were found only in winter. In summer, buildings were overcooled, and only the higher observed temperatures were within the comfort range; these were associated with decreased symptoms.

Confirmation of these findings would suggest that thermal management guidelines consider health effects as well as comfort. In winter, higher temperatures within the thermal comfort range are common in U.S. office buildings and may be associated with increased symptoms. In summer, temperatures below the thermal comfort range are common and may be associated with increased symptoms. Results from this large study thus suggest that in U.S. office buildings, less winter heating (in buildings that are in heating mode) and less summer cooling may reduce acute symptoms while providing substantial energy conservation benefits, with no expected thermal comfort penalty and, in summer, even thermal comfort benefits.

(6) *To calculate normative distributions of BRS prevalence among workers in U.S. office buildings –*

We have produced tabular summaries of distributions of specific symptom outcomes across the 97 air-conditioned study buildings, and determined in statistical models the key personal variables influencing prevalence of these symptoms. A large number of personal variables influenced symptom prevalence, even after adjustment for other personal variables, and in ways at least as strong as any identified environmental risk factor. The most important of these were gender, prior asthma diagnosis, low job satisfaction, duration of time worked in building, number of other workers in workspace. It was straightforward to provide tables of distributions for various building-related symptom outcomes, against which other buildings could be compared to see where they stood in comparison to "typical" U.S. office buildings. However, the mix of values on personal variables within a building could substantially influence the overall symptoms occurring in the building. This poses a barrier to useful interpretation of symptom prevalence in a building as a pure indicator of environmental inadequacy. In other words, if a building had many more dissatisfied, asthmatic, female workers than typical, prevalence of all symptoms could be unusually high, even in the absence of environmental factors that caused increased symptoms.

Thus we extensively explored available statistical strategies to allow comparisons of symptoms in a single building to symptoms in the set of BASE buildings, in a way that allowed adjustment for all the personal factors that might distort the desired comparison. The desired comparison might be best described as one between a single building and a set of buildings with a very similar mix of occupants who would respond identically to indoor environmental factors. We discovered that there was no apparent way to do this, because of the large number of influential personal factors, the strength of their influence relative to that of the environmental factors, and the small numbers of occupants who had provided data in the BASE buildings. The best that could be done would be to provide tables of the distribution of each type of symptom in 97 U.S. office buildings, in women only, in non-asthmatics only, in non-highly satisfied only, and so forth. But combining even two of these categories at a time was not feasible, because of small numbers.

Our conclusion was that producing user-friendly data from the BASE buildings, which could be used in conjunction with a standard symptom questionnaire for evaluating and comparing other single buildings, was not feasible, due to potential uncorrectable distortions from different mixes of personal factors in different buildings.

(7) *To combine key risks and effect modifiers identified in focused analyses described above into comprehensive models –*
The resulting comprehensive models, which adjusted previously identified risk factors for others identified in separate analyses, confirmed some prior risk factors, but not others. The following summary mentions only associations significant at the $p<0.05$ level. The primary risk factors found in these comprehensive models for increased building-related symptoms included a number associated with increases in three to five symptom outcomes: outdoor air intakes closer than 60 m to the ground (upper respiratory symptoms, eye symptoms, fatigue/difficulty concentrating, headache, and skin symptoms); polyester ventilation filters with high outdoor ozone (lower respiratory symptoms, cough, upper respiratory symptoms, eye symptoms); no carpet (lower respiratory symptoms, cough, upper respiratory symptoms, fatigue/difficulty concentrating); and poorly maintained humidification systems (skin symptoms, headache, fatigue/difficulty concentrating).

Risk factors associated with increases in two symptoms included: polyester ventilation filters with low outdoor ozone (cough, fatigue/difficulty concentrating); less frequently cleaning cooling coils and condensate drain pans (lower respiratory symptoms, headache); more efficient (MERV rating >6) ventilation filters (cough, upper respiratory symptoms); warmer winter indoor temperatures (cough, eye symptoms); presence of old (>1 year) carpet (lower respiratory symptoms, fatigue/difficulty concentrating); masonry external walls vs. glass/metal curtain/other (cough, eye symptoms).

Risk factors associated with increases in only one symptom, findings which are more susceptible to being chance associations among the many associations investigated, included current water damage in study space (eye symptoms); few or no operable windows (skin symptoms); lack of a humidification system (skin symptoms); low (<10 l/s-person) ventilation rate (lower respiratory symptoms); warmer summer indoor temperatures (cough); precast concrete or stone external walls vs. glass/metal curtain/other (eye symptoms);

It is not clear how to interpret the fact that many previously identified risk factors were not retained in these comprehensive models. Many of these variables had simplified forms to reduce the numbers of terms, which may have reduced the ability to see true associations. Also, the larger numbers of terms in these models may have made many estimates less precise.

Interestingly, these models confirmed most persuasively (e.g., with significant associations between a risk factor and three or more symptoms) were associations found for the first time in prior BASE analyses -- with outdoor air intakes closer than 60 m to the ground; polyester ventilation filters with high outdoor ozone; no carpet; and poorly maintained humidification systems. Risk factors associated with significant increases in two symptoms have also generally not been identified outside the BASE study: polyester ventilation filters with low outdoor ozone, less frequently cleaned cooling coils and drain pans, more efficient ventilation filters, warmer winter indoor temperatures, presence of old carpet, and masonry external walls. These findings, which may help explain many of the currently unexplained symptom complaints in modern commercial buildings, need confirmation and further clarification

Overall discussion

Focused analyses of environmental factors for association with building related symptoms in the BASE data identified a number of risk factors for multiple symptoms, including lower VR (even some VR above the current target rates); higher occupant density; polyester ventilation filters, especially with moderate to high levels of outdoor ozone; warmer winter temperatures even within the thermal comfort zone; and summer temperatures colder than the summer comfort zone. When these risk factors were combined in larger comprehensive models that also included prior identified risk factors in the BASE data, not all of these persisted as risk factors for multiple symptoms.

Risk factors in buildings that are considered the most likely to increase building-related symptoms, based only on our scientific knowledge, would be those related to water damage and mold, and to low ventilation rates. A limited set of factors related to moisture and mold were evaluated in the focused analyses reported here, but a broader set of factors related to moisture and mold in buildings and HVAC systems were evaluated in analyses which fed into the final comprehensive model here (aim 7). In the final comprehensive models, the set of risk factors identified somewhat persuasively (that is, by association with at least two of seven symptoms, making chance alone a less likely explanation), did include two highly plausible moisture/mold-related risk factors in HVAC systems, although not such factors in the occupied spaces: poorly maintained humidification systems, and less frequently cleaned cooling coils and drain pans. This raises the possibility that moisture-related indoor exposures are more effectively disseminated to occupants when generated within the ventilation system. Furthermore, it may indicate that systems in buildings that are designed to stay wet, that are located in the path of large quantities of airborne particles, and that also are in the path of air supplied to all building occupants, may be risks for adverse exposures to occupants.

Aside from these factors, the final comprehensive models mostly included risk factors not previously identified: outdoor air intakes closer than 60 m to the ground; polyester ventilation filters with high outdoor ozone; non-carpeted floors (relative to newer carpets); polyester ventilation filters with low outdoor ozone; *more* efficient ventilation filters; warmer winter indoor temperatures; presence of old carpet (relative to newer carpets); and masonry external walls.

<u>Conclusions</u>
The comprehensive models, which initially considered a long list of risk factors identified in the BASE data in these and prior focused analyses, identified some "expected" risk factors, and many unexpected ones. For instance, the models identified factors related to moisture and related contamination in the HVAC system

- poorly maintained humidification systems;
- less frequently cleaned cooling coils and drain pans.

One identified risk factor may indicate potential for moisture incursions into the walls:

- masonry external walls.

The models also identified factors related to outdoor air pollutants brought inside, aspects of ventilation filters, and potential interaction of outdoor pollutants with the ventilation filters:

- outdoor air intakes closer than 60 m to the ground;
- polyester ventilation filters with high outdoor ozone;
- polyester ventilation filters with low outdoor ozone;
- *more* efficient ventilation filters.

Although carpets have often been considered a potential source for chemical emissions when new, and microbial emissions when older and soiled, the comprehensive models identified the following risk factors:

- non-carpeted floors (relative to newer carpets);
- presence of old carpet (relative to newer carpets).

Newer carpets (less than one year old) were associated with the fewest symptoms; older carpets associated were associated with increase in a few symptoms, and uncarpeted floors with increases in the most symptoms.

An important different type of identified indoor risk factor was not a contaminant but a thermal parameter, yet one within a range considered acceptable

- warmer winter indoor temperatures even within the recommended thermal comfort range.

Analyses related to psychosocial stressors among workers in the BASE data confirmed that these factors are strongly associated with symptoms among indoor symptoms, but also that these are independent of associations found between symptoms and environmental risk factors. Neither type of factor explains away the other, or is even systematically associated.

This project also explored the potential for using the BASE data as a reference for interpreting the amount of symptoms in other single office buildings, as a guide to whether unusually high symptoms suggest a need to investigate adverse environmental conditions. However, we were unable to identify a feasible method to adjust such comparisons for possible effects of personal variables that may vary widely among buildings, and strongly influence symptoms, but are not amenable to preventive actions, and may produce distorted interpretations of reported symptoms.

Overall, these findings suggest potential adverse acute effects of many common features in modern commercial buildings, some expected, and many unexpected. Among other things, the findings provide the first suggestion of possible adverse effects on the health of office workers from widely used synthetic materials (generally polyester) in ventilation system filters, especially in combination with even moderately high *outdoor* ozone levels. Confirmation is of course required for all these findings, but in addition, new explanations and mechanisms will be necessary to explain any confirmed adverse affects from many these factors.

Appendix 1. Change in Specific Aim 1

Original (1): to describe the relationships between *outdoor air ventilation rates* and symptoms among indoor workers, using improved ventilation rate estimates, in order to provide input for health-protective ventilation standards for indoor workers.

Reason for revision -- before the NIOSH proposal was approved, an analysis similar to that of the original aim 1 but of smaller scope was funded by the U.S. Department of Energy. The remaining part of the analysis, plus additional elements, became the new aim 1a.

Revised (1a): To describe the associations between building-related symptoms (BRS) and outdoor air ventilation estimated in 6 ways, using estimated values for missing personal variables, comparing associations across ventilation estimation methods, and considering the feasibility of using quantitative risk assessment approaches, in order to provide input for health-protective ventilation standards for indoor workers.

Subtasks:

a) combine the BASE dataset with improved ventilation rate estimates produced for the U.S. EPA by the National Institute for Standards and Technology (NIST), and produce three kinds of ventilation rate estimates, based on air flows, CO_2 ratios, and maximum CO_2, and variables that reflect both ventilation per person and density of occupancy.
b) Produce additional metrics that estimate ventilation rate, used more conventionally in buildings, including indoor concentration of carbon dioxide (CO_2); average difference between indoor and outdoor CO_2 concentration, and maximum difference between indoor and outdoor CO_2 concentrations.
c) Impute missing values for personal variables in the BASE data, based on the best current methods, to increase power and decrease bias in analyses
d) Produce models to estimate relationships of these five ventilation estimates with symptom outcomes among occupants in BASE. Explore these relationships for evidence of thresholds, dose-response relations, and non-linear relationships
e) Compare findings across all ventilation rate estimates.
f) Recommend which ventilation metrics, based on these findings, are most appropriate to use in assessing minimum ventilation rates for indoor work environments
g) Assess adequacy of the BASE data for using a novel “risk assessment” approach not yet applied to setting health-protective indoor ventilation guidelines

Appendix 2. Change in Specific Aim 2

Original (2): To assess risks for symptoms among indoor workers from *sources of indoor chemical emissions*, including surface materials and cleaning products.

Reason for revised aim -- We discovered that the variables for this aim were of limited use for analysis, due to missing, ambiguous, or insufficiently varying values.

Revised (2a): To assess whether psychosocial factors in offices are risks for BRS among indoor workers and whether psychosocial factors confound associations of BRS with building-related risk factors.

The bulk of published research on building-related symptoms (BRS) in office buildings has focused on environmental risk factors, such as physical, chemical, or biological factors, and not on psychosocial risk factors, such as job stress, job satisfaction, job demand, or job control. Many BRS studies have assessed work-related psychosocial factors in the occupant questionnaire, along with the symptom outcomes of interest. However, these studies generally have not reported magnitude of risks associated with psychosocial factors, but have statistically adjusted for the psychosocial factors to avoid confounded estimates for the environmental risk factors of primary interest.

Few studies have reported the relative risks of increased symptoms associated with psychosocial factors in offices, and even fewer have reported risks of psychosocial factors when adjusted for the risks of environmental factors. Based on the few available reports, psychosocial factors at work have been strongly associated with symptom reporting, but in models containing both psychosocial factors and objectively assessed environmental factors, both types of factors were independently associated with increased symptoms among office workers.

In contrast, a recent publication in the journal Occupational and Environmental Medicine, based on a large study of office workers in the U.K., reports that only psychosocial and not environmental matters have important relationships with worker symptoms (Marmot, Eley et al. 2006). The article further suggests that those attributing responsibility for symptoms in offices to environmental factors are likely to be mistaken because they have failed to assess the *true* cause of these symptoms: psychosocial stressors at work. We have submitted a letter to the journal (see Appendix 1) pointing out many limitations of this study and its report.

We will conduct analyses of the U.S. EPA BASE study, investigating associations between psychosocial stressors in the workplace and building related symptoms, and their relationship to associations identified in other analyses between environmental factors and symptoms. The BASE data include, from a representative sample of 100 U.S. office buildings, information on participants' symptoms, job factors, other personal factors, and many measured and observed environmental factors in the buildings.

Subtasks:

a) identify available data variables in BASE on psychosocial stressors in the workplace (including job type, job satisfaction, job conflict, job demand, and job clarity).
b) estimate unadjusted associations between psychosocial stressors and symptoms

c) using multivariate risk estimation models, investigate changes in unadjusted estimates when adjusted for environmental risk factors in the BASE data, and vice versa.
d) summarize findings in a report that includes a brief review of previous related findings on these questions.

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Relationship to specific aims: reports findings of analyses related to specific aim 5

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Relationship to specific aims: one of two papers reporting findings of analyses related to specific aim 3

Buchanan I, Mendell MJ, Mirer A, Apte M: [2008] Air filter materials, outdoor ozone and building-related symptoms in the BASE study. Indoor Air 18: 144–155.

Relationship to specific aims: one of two papers reporting findings of analyses related to specific aim 3

Mendell MJ, Lei-Gomez Q, Apte M: [2008] Ventilation rate (estimated three ways) and building-related symptoms in U.S. office buildings – the U.S. EPA BASE study. Proc of Indoor Air 08: the Eleventh International Conference on Indoor Air Quality and Climate, Copenhagen, #158, Aug 17-22.

Relationship to specific aims: reports findings of analyses related to specific aim 1

Reports in preparation

Mendell MJ, Mirer A, Lei-Gomez Q. Building-related symptoms in the U.S. EPA BASE Study: potential use as reference data.

Relationship to specific aims: will report findings of analyses related to specific aim 6

Mendell MJ, Mirer A. A comprehensive model of risk factors for building-related symptoms in the U.S. EPA BASE Study.

Relationship to specific aims: will report findings of analyses related to specific aim 7

Mendell MJ, Mirer A, Psychosocial factors in offices as risk and confounding factors for building-related symptoms in the U.S. EPA BASE Study.

Relationship to specific aims: will report findings of analyses related to specific aim 2a

Mendell MJ, Lei-Gomez Q, Apte M. Comparing metrics for ventilation rate in predicting work-related symptoms in U.S. office buildings – the BASE study.

Relationship to specific aims: will report findings of analyses related to specific aim 1a

Inclusion of gender and minority study subjects

The racial and ethnic proportions of the population responding to the original U.S. EPA questionnaire and included in these analyses are unknown. The EPA, in designing this questionnaire in the early 1990's, apparently decided that requesting this potentially sensitive information would diminish response, so unfortunately no questions on race and ethnicity were included. However, because this was a study of representative U.S. office buildings, the study population is likely to contain a broad mix of various racial and ethnic groups. In a previous representative study of office workers in the San Francisco Bay Area of California, questions that did not distinguish race and ethnicity determined that the racial and ethnic mix was 46% White non-Hispanic; 16% Black, 24% Asian/Pacific Islander, 10% Hispanic, and 4% other (Mendell, 1991).

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Inclusion of Children

Children were not explicitly included or excluded in this occupational research, intended to include a representative sample of U.S. office buildings and office workers. Participation by children (i.e., defined as up to age 20) was possible, but most likely limited in the office workforce to those between the ages of 18-20. Because responses to the "age" question identified only age intervals, it is possible to know precisely the number of participants under age 20, but not those of exactly age 20. The study population included 35 workers (0.8% of the total) under 20 years of age. The next higher age category, 20-29 years of age, is likely to have included 20-year-olds among the 662 workers (15.4%) in the category.

Research focused on the health effects of indoor environments of children is of great importance, but is more effectively conducted in residential, school, and day care settings than in office settings.

Materials available for other investigators

NA