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# AN SAB ADVISORY: Building Assessment and Survey Evaluation (BASE) Study Propos Data Analyses

## PREPARED BY THE INTEGRATED HUM EXPOSURE COMMITTEE (IHEC) OF THE SCIENCE ADVISORY BOARD (SAB)

April 22, 1999

EPA-SAB-IHEC-ADV-99-008

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: Advisory on the Building Assessment Survey Evaluation (BASE) Study Proposed Data Analyses

Dear Ms. Browner:

The Integrated Human Exposure Committee (IHEC) of the Science Advisory Board met on March 9, 1999 in Washington, DC to conduct an advisory on the proposed data analyses for the Building Assessment Survey Evaluation (BASE) study. The BASE study was designed by the EPA Office of Radiation and Indoor Air in response to the Agency's responsibility to gather information and disseminate guidance regarding indoor air quality (IAQ) health risks under Title IV of the Superfund Amendment Reauthorization Act and in response to the Government Performance and Results Act (GPRA) Goal 4, Objective 4 which states that "By 2005, 15 million more Americans will live or work in homes, schools, or office buildings with healthier indoor air than in 1994." In this advisory, the Committee is providing advice on the analysis of the data which have been recently collected.

BASE is a cross-sectional multi-year study designed to define key characteristics of IAQ in 100 public and commercial buildings. The BASE project has four goals:

a) to collect baseline data characterizing public and commercial office buildings,

b) to establish information on important indoor air parameters for policy decisions and guidance development,

c) to examine the relationships among parameters and between parameters and occupants' perceptions and symptoms, and

d) to serve as a basis for hypothesis development.

The Committee was charged to respond to the following Charge questions:

a) Are the proposed data analyses the most relevant?;

b) Does the Committee have advice on additional analyses that should be considered?**;**

c) How should the analyses be prioritized considering the need to address relevant scientific issues and the most important programmatic goals identified by the Agency? In prioritizing the analyses, which analyses are essential given the Agency's need to address relevant scientific issues and the most important programmatic goals identified by the Agency?; and

d) Are there similar analyses (that have been conducted on other data sets) that EPA should use as guidance in its data analysis efforts?

The ultimate goal of the BASE study is to improve public health through improvements in indoor air quality. To reach this goal, it is necessary to establish baseline information about the characteristics of indoor air in different buildings, in different locations, and under different conditions. The frequency distributions of the normative data are the hallmark of this project and should be extremely useful in supplying relevant and useful yardsticks to practitioners studying indoor air. Specifically, the BASE data will provide the EPA with building profiles, including distributions for the concentration of various toxicants indoors, building operational characteristics and frequencies of various symptom complaints. Therefore, the IHEC found the BASE survey to be extremely important and commends the Agency personnel who have steered this complex and carefully executed data collection effort to completion.

Overall, the Committee found the proposed analyses to be the most relevant and extremely useful in providing significant data on the contributions of indoor environments to human exposure and adverse health. The Committee found the overall proposed analyses to be useful in helping the Agency to meet GPRA Goal 4, Objective 4. The analyses of the study parameters can also be useful in determining good IAQ practices and, subsequently, in helping the EPA to achieve its GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. The IHEC highly encourages the Agency to integrate the BASE project into the Agency's efforts to analyze cumulative exposure (SAB, 1996) to maximize the impact of BASE on the overall protection of public health.

The IHEC strongly recommends that the Agency focus on conducting Quality Assurance/Quality Control on the data followed by evaluating the descriptive statistics, in-depth, in order to provide critically needed baseline information on the various parameters that have been monitored in the 100 commercial and public buildings that were included in the study. The Committee urges the Agency to release the information to the public as soon as the QA/QC and descriptive statistics analysis are completed. The Committee recommends that the Agency consider conducting more complex analyses such as testing for associations after the descriptive statistical data are released. The Committee makes several recommendations for the subsequent analysis of the data. The IHEC emphasized that the Agency should determine (a priori) the acceptable power before testing for associations. As an evaluation tool to assist the Agency further in responding to this question, the IHEC recommends that the EPA consider using a matrix, assigning point values according to the contribution of each analysis to each GPRA or program goal. This type of system could make it easier for the Agency to identify high priority analyses.

The IHEC recommends that the Agency incorporate guidelines regarding the scientific limitations in using the data. Such guidelines would reduce the likelihood that the data are misinterpreted and that invalid associations are inferred and would minimize the likelihood of data dredging (analyzing the data without adequately incorporating the uncertainties associated with the data), especially given the large number of variables in the study.

In citing a few data sets with analyses that EPA may be able to use as guidance in its data analysis efforts, the Committee emphasizes the importance of analyzing both the BASE data and the data from the Office of Research and Development longitudinal study, the Temporal Indoor Monitoring and Evaluation (TIME) Study. Conducted by the EPA's Office of Research and Development, the same core parameters from BASE were collected in a smaller number of buildings in the TIME study. However, unlike the BASE study, samples in the longitudinal study were taken over different seasons (Fortmann, 1994; EPA, 1999). TIME has the potential, when coupled with the BASE study, to provide valuable information on the relationships between cross-sectional and longitudinal studies. Therefore, the Committee strongly encourages the Agency to review and compare results from both cross-sectional and longitudinal studies simultaneously to make sure that necessary and comparable analyses are carried out on the data of both studies. The Committee also encourages the Agency to establish collaborative relationships with other researchers when developing the strategy to conduct the BASE analyses and when conducting the BASE analyses.

The Committee appreciates the opportunity to provide advice to the Agency on the BASE data analyses and looks forward to receiving a written response from the Assistant Administrator for Air and Radiation (OAR).

Sincerely,

/signed/
Dr. Joan M. Daisey, Chair
Science Advisory Board

/signed/
Dr. Henry A. Anderson, Chair
Integrated Human Exposure Committee
Science Advisory Board

# NOTICE

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# ABSTRACT

The Integrated Human Exposure Committee (IHEC) of the Science Advisory Board met on March 9, 1999 in Washington, DC to conduct an advisory on the proposed data analyses for the Building Assessment Survey Evaluation (BASE) study. BASE is a cross-sectional multi-year study designed to define key characteristics of IAQ in 100 public and commercial buildings. The ultimate goal of the BASE study is to improve public health through improvements in indoor air quality.

Overall, the Committee found the proposed analyses to be the most relevant and extremely useful in providing significant data on the contributions of indoor environments to human exposure and reported symptoms. The BASE data is expected to be normative (typical of public and commercial buildings) because the buildings used in the study were randomly selected. The frequency distributions of the normative data are the hallmark of this project and should be extremely useful in supplying relevant and useful yardsticks to practitioners studying indoor air. The Committee found the overall proposed analyses to be useful in helping the Agency to meet GPRA Goal 4, Objective 4, which states that "By 2005, 15 million more Americans will live or work in homes, schools, or office buildings with healthier indoor air than in 1994." The analyses of the study parameters can also be useful in determining good IAQ practices and, subsequently, in helping the EPA to achieve its GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. The IHEC highly encouraged the Agency integrate the BASE project into the Agency's efforts to analyze cumulative exposure in order to maximize the impact of BASE on the overall protection of public health.

The IHEC strongly recommended that the Agency focus on conducting Quality Assurance/Quality Control on the data and then conduct an in-depth evaluation of the descriptive statistics in order to provide critically needed baseline information on the various parameters that have been monitored in the 100 commercial and public buildings that were included in the study. The Committee urged the Agency to release the information to the public as soon as the QA/QC and descriptive statistics analyses are completed. It was recommended that more complex analyses, such as testing for associations, be considered after the baseline data are released. The IHEC provides several recommendations for the subsequent data analyses. The IHEC emphasized that the Agency should determine (*a priori*) the acceptable power before testing for associations.

The IHEC recommended that the Agency incorporate guidelines regarding the scientific limitations in using the data. Such guidelines would reduce the likelihood that the data are misinterpreted or that invalid associations are inferred and would minimize the likelihood of data

dredging, especially given the large number of variables in the study. The Committee cited a few data sets with analyses that EPA may be able to use as guidance in its data analysis efforts and emphasized the importance of analyzing both the BASE data and the data from the Office of Research and Development longitudinal study, the Temporal Indoor Monitoring and Evaluation Study (TIME). The Committee also encouraged the Agency to establish collaborative relationships with other researchers when developing the strategy to conduct the BASE analyses and while conducting the BASE analyses.

Keywords: Building Assessment Survey and Evaluation Study (BASE); indoor air; indoor air quality (IAQ); indoor environments; human exposure; Government Performance and Results Act (GPRA); and cumulative exposure; Temporal Indoor Monitoring and Evaluation Study (TIME).

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# 1. EXECUTIVE SUMMARY

The Integrated Human Exposure Committee (IHEC) of EPA's Science Advisory Board, supplemented by a radon expert (a liaison from the SAB Radiation Advisory Committee), met on March 9, 1999 to review the proposed data analyses for the Building Assessment Survey and Assessment (BASE) study. The purpose of BASE is to help fill the significant data gap regarding baseline indoor air quality (IAQ) in public and commercial office buildings in the United States. This study was conducted by the EPA Office of Radiation and Indoor Air (ORIA).

The Committee addressed the following Charge questions:

a) *Are the proposed data analyses the most relevant*? - Overall, the Committee found the proposed analyses to be the most relevant and extremely useful in providing significant data on the contributions of indoor environments to human exposure and reported symptoms. The Committee also found the overall proposed analyses to be useful in helping the Agency to meet GPRA Goal 4, Objective 4, which states that "By 2005, 15 million more Americans will live or work in homes, schools, or office buildings with healthier indoor air than in 1994." The analyses of the study parameters can also be useful in determining good IAQ practices and, subsequently, in helping the EPA to achieve its GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. The IHEC highly encouraged the Agency integrate the BASE project into the Agency's efforts to analyze cumulative exposure (SAB, 1996) in order to maximize the impact of BASE on the overall protection of public health.

b) *Does the Committee have advice on additional analyses that should be considered?* - The Committee recognized the significant effort that the Agency has undertaken in performing this study. As mentioned in the previous section, overall, IHEC found that the data analysis being proposed is adequate and comprehensive. In an effort to facilitate getting the normative information in the published literature, the Committee hesitated to recommend additional analyses that may be useful to perform since those analyses are not as critical in the near-term. The BASE data is expected to be normative (typical of public and commercial buildings) because the buildings used in the study were randomly selected. Thus, in performing the current analyses, the Committee recommended a focus on the QA/QC of the available data that will facilitate publishing quality data that may be used by the Agency and others in future evaluations. The IHEC provided advice on the subsequent data analysis and commented on: the

aggregation of the data; uncertainty analysis; the classification of chemicals; testing for associations; confounding factors; psychosocial stress; the building symptoms index; and the sampling protocol. The Committee encourages the Agency to work with other organizations to define and perform these additional analyses.

c) *How should the analyses be prioritized considering the need to address relevant scientific issues and the most important programmatic goals identified by the Agency? In prioritizing the analyses, which analyses are essential given the Agency's need to address relevant scientific issues and the most important programmatic goals identified by the Agency?* - The IHEC strongly recommended that the Agency focus on conducting Quality Assurance/Quality Control on the data followed by evaluating the descriptive statistics, in-depth, in order to provide critically needed baseline information on the various parameters that have been monitored in the 100 commercial and public buildings that were included in the study. The Committee urged the Agency to release the information to the public as soon as the QA/QC and descriptive statistics analyses are completed. The Committee recommended that the Agency consider conducting more complex analyses such as testing for associations after releasing the data on the descriptive analysis. The IHEC emphasized that the Agency should determine (a priori) the acceptable power before testing for associations.

d) *Are there similar analyses (that have been conducted on other data sets) that EPA should use as guidance in its data analysis efforts?*- There are many similar analyses that have been conducted on other data sets, essentially too numerous to list. There are multiple studies in the literature (including proceedings from Indoor Air & Healthy Buildings) of which the EPA staff in the Office of Air and Radiation, Office of Radiation and Indoor Air, Indoor Environments Division are aware. The IHEC cited four data sets with analyses that may be useful as guidance in EPA's data analysis efforts. Those data sets are from the following studies are: the California Healthy Building Study, the European Audit Project to Optimize Indoor Air Quality and Energy Consumption in Office Buildings, the Japanese Office Building Survey and the TEAM study. The Committee also emphasized the importance of reviewing and comparing results from both BASE and the Temporal Indoor Monitoring and Evaluation Study (TIME).

# 2. INTRODUCTION

## 2.1 Background

BASE is a cross-sectional, multi-year study designed to define key characteristics of IAQ in 100 public and commercial buildings. The BASE project has four goals:

a) to collect baseline data characterizing public and commercial office buildings,

b) to establish information on important indoor air parameters for policy decisions and guidance development (a list of the parameters is included in Appendix B),

c) to examine the relationships among parameters and between parameters and occupants' perceptions and symptoms, and

d) to serve as a basis for hypothesis development.

Buildings were randomly selected from cities with a population of at least 100,000 in 10 climatic regions. Businesses were also selected randomly using business listings obtained for a given city. In order for a business to be included in the BASE study, the building owner/management had to be willing to participate, the building could not be highly publicized as a "sick" or "problem" building, and the building had to meet the study area criteria. In the BASE study, the study area criteria was defined as a building which is served by no more than two air handlers, houses a minimum of 50 employees, and has a maximum of 3 floors.

In the 100 buildings selected for the BASE study, specific environmental measures were taken, building and heating, ventilation, and air-conditioning (HVAC) characteristics were defined, and occupant questionnaires were completed. A list of the specific core parameters and measurements taken are provided in Attachment B. Examples of environmental measures included temperature, relative humidity and carbon dioxide measurements. Some of the building characteristics that were recorded included building use, occupancy and smoking policy. The Indoor Environmental Quality Questionnaire included questions on job characteristics, health and well-being of the occupant, and work place environmental conditions such as the cleanliness of the workspace and the lighting conditions (EPA, 1994). The sampling sites and the schedule of measurements and equipment were also described in the standardized BASE protocol (EPA, 1994). All measurements were taken over the course of a week, from Monday to Friday. Specifically, some environmental measures such as relative humidity, carbon dioxide and carbon monoxide were sampled continuously from Tuesday to Thursday. For those samples, the Agency recorded 5 minute averages. Integrated sampling was used to measure the concentration of

VOCs, particles, and formaldehyde, resulting in 8-9 hour exposure levels. Also, the bioaerosols were only sampled for 2 minutes and 5 minutes twice on Wednesday.

The EPA has completed field measurements on 100 public and commercial buildings. Some summary statistics have been completed for VOCs (volatile organic compounds), fungi, and particulate matter (PM). Some of the data analysis that is underway includes: QA/QC for the data for the last 14 buildings included in the study; the evaluation of the representativeness of buildings (compared with the Department of Energy (DOE) survey-DOE, 1995); the evaluation of the precision and accuracy of the data; and the calculation of ventilation rates of the buildings that were included in the survey.

The Agency developed a proposed plan for the data analysis that was designed to best address relevant scientific issues and the most important programmatic goals identified by the Agency. The Agency's proposed data analysis is included as Appendix C and is listed in order of priority. Specifically, the data analysis plan was developed based on the Government Performance and Results Act (GPRA) goals, especially GPRA Goal 4, Objective 4 which is included in Appendix D. In the proposed BASE analysis plan, EPA has identified and prioritized six types of analyses. Those analyses include: a) quality assurance/quality control; b) representativeness of the building samples and weighting determinations; c) ventilation rate calculations - % outdoor air, air exchange rate and the amount of cubic feet per minute of air per occupant; d) frequency distribution (for normative data); e) associations; and f) indices and measures. A description of those analyses is provided below.

a) *Quality Assurance/Quality Control* - EPA plans to conduct a quality assurance/quality control analysis first to review the data for errors, needed changes, or missing data. In this QA/QC procedure, the EPA also plans to determine the accuracy and precision of the data.

b) *Representativeness of Building Samples and Weighting Determinations* - The representativeness of the buildings samples was selected as the second analysis. The Agency plans to compare regional frequency distributions of building characteristics such as occupancy, building age, gross floor area, and the number of floor to those found in the DOE study; to examine any potential biases resulting from the building selection process; and to develop nationally representative distributions (DOE, 1995).

c) *Ventilation Rate Calculations - % outdoor air, air exchange rate and CFM/occupant* - After conducting analyses on the representativeness of the

buildings, the Agency plans, as the third analysis, to calculate the ventilation rates to determine the percent of outdoor air, air exchange rate and the cubic feet per minute (CFM) of air per occupant.

d) *Frequency Distribution (normative data)* - The fourth analysis, the frequency distributions (on normative data) would be determined for several of the core parameters, including concentrations of environmental measurements, symptoms reported on the occupant questionnaire, building maintenance practices, occupant demographics, comfort parameters (such as continuous temperature, relative humidity, sound and light), and sources (such as furnishings, computers, cleaning materials, and cigarette smoke). (The BASE data is expected to be normative (typical of public and commercial buildings) because the buildings used in the study were randomly selected.)

e) *Associations* - In its fifth analysis, the Agency proposes to test for associations between the core parameters such as the relationships among symptoms, demographics, environmental parameters, and building and HVAC characteristics.

f) *Developing Indices and Measures* - Finally, in its sixth analysis, the EPA proposes to develop indices and measures including indices for building symptoms, indoor pollutants, and building system quality.

## 2.2 The Review and Charge

On March 9, 1999, the Integrated Human Exposure Committee met in Washington, DC to conduct an advisory on the proposed data analyses for the Building Assessment Survey and Evaluation (BASE) project. The IHEC was charged to respond to four questions. These questions and the responses by IHEC are presented in the next section.

# 3. RESPONSE TO CHARGE QUESTIONS

## 3.1 General Findings

Overall, the Committee found the proposed analyses to be the most relevant and extremely useful in providing significant data on the contributions of indoor environments to human exposure and reported symptoms. The BASE data is expected to be normative (typical of public and commercial buildings) because the buildings used in the study were randomly selected. The frequency distributions of the normative data are the hallmark of this project and should be extremely useful in supplying relevant and useful yardsticks to practitioners studying indoor air. The Committee also found the overall proposed analyses to be useful in helping the Agency to meet GPRA Goal 4, Objective 4. The analyses of the study parameters can be useful in determining good IAQ practices which can ultimately help the EPA to achieve their GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. The IHEC recommends that the Agency integrate the BASE project into the Agency's efforts to analyze cumulative exposure.

The IHEC strongly recommends that the Agency first focus on conducting Quality Assurance/Quality Control on the data and then focus on evaluating the descriptive statistics, in-depth, in order to provide critically needed baseline information on the various parameters that have been monitored in the 100 commercial and public buildings that were included in the study since this is the heart of BASE. The Committee urges the Agency to release the information to the public as soon as the QA/QC and descriptive statistics analysis are completed. The Committee recommends that the Agency considers conducting more complex analyses such as testing for associations only after the data on the descriptive analysis have been released. The IHEC emphasizes that the Agency should determine (*a priori*) the acceptable power before testing for associations.

The IHEC strongly recommends that the Agency, for additional analyses, incorporate guidelines regarding the scientific limitations in using the data, e.g., to reduce the likelihood that the data are misinterpreted or that invalid associations are inferred. It will also be necessary to develop procedures to minimize the likelihood of data dredging, especially given the large number of variables in the study. This may be particularly important in using the data on symptoms in conjunction with the data on the building characteristics. The Committee also cites a few data sets with analyses that EPA may be able to use as guidance in its data analysis efforts, and emphasizes the importance of analyzing both the BASE data and the data from the Office of Research and Development longitudinal study, the Temporal Indoor Monitoring and Evaluation

(TIME) study. The Committee also encourages the Agency to establish collaborative relationships with other researchers when developing the strategy to conduct the BASE analyses and while conducting the BASE analyses.

### 3.2 Charge Question 1: Relevance of the Proposed Data Analyses

*Are the proposed analyses the most relevant?*

The Committee found the proposed analyses to be the most relevant and extremely useful to those who are concerned with the contribution of indoor environments to human exposures. IHEC commends the Agency personnel who have steered this complex and carefully executed effort to completion. The Committee also found the overall proposed analyses to be useful in helping the Agency to meet GPRA Goal 4, Objective 4. For example, the associations between symptoms, environmental parameters and building and HVAC characteristics could be useful in determining good IAQ practices. These practices could then be publicized to help building owners to improve their IAQ practices and to help EPA to achieve their GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. The IHEC strongly recommends that the Agency integrate the BASE project into its cumulative exposure efforts such as the National Human Exposure Assessment Survey (NHEXAS) project and the Cumulative Exposure Project (SAB, 1996). As an evaluation tool to assist the Agency further in responding to this question, the IHEC recommends that the EPA consider using a matrix, assigning point values according to the contribution of each analysis to each GPRA or program goal. This type of system could make it easier for the Agency to identify high priority analyses.

The Committee recommends that the Agency modify the prioritization of the data analyses to begin with Quality Assurance/Quality Control analyses, followed by an analysis of frequency distributions, and then an analysis of ventilation rate calculations. The frequency distribution analysis should also include an examination of the shape of the distribution, in addition to an examination of medians and interquartile ranges. Before proceeding with the frequency distribution analysis, the Agency should reevaluate non-detect values using more recent approaches (including simulation/Monte Carlo analyses). The IHEC recommends that the analyses of the associations and indices be placed at the bottom of the priority list of the data analyses. More specific advice on the prioritization of the data analyses is provided in the Committee's response to Charge question 3 in Section 3.4 of this report.

a) *Associations* - There was some concern that there may be a temptation to select the types of associations based on curiosity as opposed to significance,

especially given the large number of associations that the Agency could analyze.

b) *Averaging the data* - There was also a concern that important information on outliers and sensitive populations would be lost by averaging the data. Specific recommendations regarding these concerns are provided in the Committee's response to Charge question 2 in Section 3.3 in the discussion on the aggregation of the data.

c) *Reliance on subjective reports of symptoms* - There was a concern that the current study depends solely on subjective reports of symptoms, rather than actual signs of health effects. The occupant questionnaire included several subjective questions about employee health and well-being. Inclusion of analyses on both signs and symptoms would have provided a more complete picture of indoor air quality. Therefore, the Committee recommends that in future studies on indoor air quality, the Agency consider including more objective health data such as physical exams and biomarkers. For example, a short physical exam could include observations for dermatitis or wheezing. Also, several biomarkers exists for determining the presence of various chemicals or their metabolites in the body, including several VOCs and pesticides.

d) *Potential sources of indoor air quality lacking adequate data in the BASE study* - The Committee recommends that, in future studies, the Agency include more information on pesticide exposure, allergens, and cleaning agents in order to provide a more complete picture of their significance as sources for IAQ complaints and IAQ-related health effects. For example, the EPA Indoor Environmental Quality Survey, does not mention pesticides or pesticide exposures. The monitoring checklist on page D-4 of the supplement does include pesticides. However, this informal monitoring, apparently performed only twice during one day of the study, depends on actual observations of pesticide application which would be unlikely during the hours when the study was done. The IHEC was also concerned that the BASE protocol does not include specific information about cleaning agents or specific allergens. Some cleaning agents are potential sources of indoor exposure to hazardous chemicals via aersolization and dermal exposure. The building maintenance workers, who typically clean at night, would, in general, have more detailed knowledge of these sources than building occupants.

### 3.3 Charge Question 2: Additional Analyses That Should Be Considered

*Does the Committee have advice on additional analyses that should be considered?*

The Committee recognizes the significant effort that the Agency has undertaken in performing this study. As mentioned in the previous section, overall, the data analysis being proposed is adequate and comprehensive. In an effort to facilitate getting the normative information in the published literature, the Committee hesitates to recommend additional analyses that may be useful to perform since those analyses are not critical in the near-term. Thus, in performing the current analyses, the Committee recommends a focus on the QA/QC of the available data, which will facilitate publishing quality data that may be used by the Agency and others in future evaluations. The Committee encourages the Agency to work with other organizations to define and perform these additional analyses.

The Committee provides several recommendations on some of these subsequent analyses. However, the contextual framework and the issues to be explored using the data will have a strong influence on whether additional analysis will be required. Since the analytical models are still being developed, the Committee recommends that the following factors be considered in the data analysis.

a) *Aggregation of the data* - There are concerns that in aggregating data, valuable information may be lost. The need to provide the normative frequency distributions is viewed as more important than developing nationally representative distributions, particularly for example, for any parameters that are best described on a regional basis (e.g., construction type).

Another concern is that by averaging the data into frequency distributions, one could lose the power of looking at the outlier data. Thus, in developing distributions, there should be a discussion of the statistical rigor, or at a minimum the level of confidence/uncertainty, with which any distribution is developed. The shape of the distributions should be examined, not just the medians and interquartiles. Also, the relevance of outliers should be addressed.

However, it may be appropriate to group some types of parameters, including chemicals, to reduce the total number of analyses. Any effort to do so should be carefully examined to ensure that the grouping is appropriate as described below.

b) *Analyzing classes of chemicals and individual chemicals* - An effort should be made to classify the chemicals into a small number of categories in order to facilitate the use of the data in risk analysis. There are several classification schemes that relate the chemical properties of compounds to the toxicity potential. However, the IHEC also recommends that the Agency analyzes individual chemicals in addition to classes of chemicals since both may be found have a significant effect on indoor air quality. The IHEC recommends that the Agency start with structure-activity relationships for the health outcomes that were monitored during the study.

Although the use of "toxicity equivalence units" has inherent flaws, the fact that people are exposed to a mixture of indoor air contaminants at any given time should be realized. In September 1998, the IHEC reviewed the disproportionate impact methodologies that the Agency was proposing to use to help it respond to complaints filed under Title VI of the Civil Rights Act of 1964 that allege discriminatory effects from the issuance of pollution control permits by states or other governmental bodies that receive financial assistance from EPA. Those methodologies included the use of “toxicity equivalence units.” (SAB, 1999).

c) *Uncertainty analyses* - The uncertainty in data for any collected parameter should be addressed, as far as possible. The Committee found the proposal for performing the stated QA/QC analyses to be appropriate. However, the IHEC recommends that the Agency include the level of confidence in the reported data for factors (e.g., smoking policy) that cannot be absolutely defined. It was also recommended the non-detect values be re-evaluated using more current approaches like Monte Carlo simulation methods.

d) *Associations* - Although categories of associations are listed, no specific ones are defined. After providing the normative data, this type of analyses is considered the most useful. Methods to perform the analyses include simple pattern analysis using the raw data, development of building profiles, and multivariate and stratified analyses. When conducting multivariate and stratified analyses, the Agency should consider using demographic risk factors and building risk factors as covariates and/or effect modifiers. (Risk indices could be calculated for individuals and for buildings, as well as the other indices indicated. These risk indices could then be used in the analyses). This is especially important in looking at the simplistic symptoms (and indices) in

relation to environmental parameters (where other "complaints" are treated as confounders) and/or building/HVAC characteristics. Before conducting multivariate analyses, the Agency should first determine if there is colinearity between any of the core parameters such as between contaminants and between contaminants and HVAC characteristics. However, care should be exercised in performing these analyses because of the danger of defining cause and effect interpretations where none exist.

e) *Confounding factors* - Confounding factors must be considered in any effort to establish causal relationships in the data. For instance, in analyzing the data, the Agency should control for the effects of existing medical conditions when trying to establish the relationship between exposure and reported symptoms since the symptoms themselves may not be independent variables. The Committee expressed some concern about the utility of the occupant questionnaire given the possibility of a healthy worker bias since sick workers may not have been captured during the questionnaire process. The study was designed to address some confounders and cofactors. Therefore, it is particularly important that the EPA clearly document the limitations in use of the data in the exposure-response assessment. For future analyses of the worker well-being, the IHEC stresses the importance of obtaining information from employees on sick leave.

f) *Psychosocial factors* - The psychosocial factors (work stressors, at-home stressors, ergonomic factors of lighting, office comfort and proximity to windows) should be included in the assessment of relationships between exposure and health outcomes (symptoms). The association of psychosocial stressors with the reported symptoms may be particularly important in the population under study.

g) *Building Symptoms Index (BSI)* - The Building Symptoms Index is based on six self-reported symptoms that improve when occupants are away from work. Those symptoms include: dry, itching or irritated eyes; headache; sore or dry throat; unusual tiredness, fatigue or drowsiness; stuffy or runny nose, or sinus congestion; and dry or itchy skin. The IHEC found that the concept of Building Symptoms Index (BSI) needs further development to increase its power as a risk assessment tool. The BSI is calculated by averaging, for each building, the Personal Symptoms Index (PSI) values. Each PSI value is calculated by adding the number of the six symptoms reported by each occupant (Brightman, 1996). The assumption that each factor contributes equally to the "total" symptom may be unrealistic in many instances. The IHEC recommends that the Agency consider using a weighting that takes into account the importance of key risk factors (in the indoor environment) and the severity of the symptoms.

Since the "symptoms" are so non-specific, the development of "indices" that may be subsequently used in cause and effect relationships should be carefully evaluated. Any subsequent interpretations using these "indices" should be based on analyses that relate effects not only to exposure (because of the presence of the material) but should be compared to "environmental levels" that would be expected to produce "effects" consistent with symptoms or other adverse effects.

h) Sampling Schedule - Some environmental measures such as relative humidity, carbon dioxide and carbon monoxide were sampled continuously from Tuesday to Thursday. For those samples, the Agency has recorded 5 minute averages. However, integrated sampling was used to measure the concentration of VOCs, particles, and formaldehyde, resulting in an 8-9 hour exposure level. Given the limitations of current technologies for bioaerosol sampling, the bioaerosols were only sampled for 2 minutes and 5 minutes twice on Wednesday. The Committee was concerned that measurements without continuous data, such as the VOCs and particles would be of limited utility in testing for associations with acute health effects (e.g., asthma which is a chronic condition that is aggravated by acute attacks).

The Committee offers the following general discussion to assist the EPA in putting context around additional studies as well as specific recommendations on additional/alternate

analyses, should the Agency have the resources to perform these. The Committee recommends that the Agency consider:

a) analyzing in other indoor environments, including residences and day care centers;

b) identifying one environmental parameter that is a good indicator of overall building air quality so that all environmental parameters do not have to be measured;

c) analyzing indoor air to protect "sensitive" populations as well (the current analyses are designed to protect the "average" person);

d) determining the correlation between outdoor air quality and indoor air quality;

e) conducting longitudinal studies, e.g., evaluating overlapping buildings in the ORD study that was carried out over time; and

f) determining whether the buildings with the highest level of concern for a given environmental parameter are also found to be the same buildings with the highest levels of concern for another parameter (e.g., determining if buildings with the highest levels of fungi were also the same buildings with the greatest amount of water damage and if the buildings with the highest levels of VOCs are the same buildings with the most reported symptoms).

### 3.4 Charge Question 3: Prioritizing the Data Analyses

*How should the analyses be prioritized considering the need to address relevant scientific issues and the most important programmatic goals identified by the Agency? In prioritizing the analyses, which analyses are essential given the Agency's need to address relevant scientific issues and the most important programmatic goals identified by the Agency?*

The Committee recommends that the Agency first discard incomplete and unreliable data before it analyzes the data. The Agency's proposed data analysis is included as Appendix C and is listed in order of priority. The Committee concurs with the Agency's placement of the QA/QC at the top of the list. However, the Committee's recommendations for the prioritization of the other data analyses is different from that proposed by the Agency. The IHEC recommends that the EPA focuses on the outlined frequency distribution first, after

conducting the QA/QC. The IHEC recommends analysis on the frequency distribution for the second analysis since baseline data is the heart of BASE. This analysis provides baseline information on the various parameters that have been monitored in the 100 commercial and public buildings that were included in the study. After conducting the analysis on the frequency distributions, the Agency should then calculate the ventilation rates. The Committee places the analyses on the representativeness of the buildings and the analyses on association at the bottom of the list of priorities. If, at some point, regional weighting factors are developed and employed, the Committee urges the Agency to be quite explicit when presenting data summaries to indicate whether the data are weighted or unweighted. As noted in the Committee's response to Charge question 2, the Agency should consider analyzing indoor air, in the future, to protect "sensitive" populations.

a) *Frequency Distributions* - The frequency distributions of the normative data are the hallmark of this project and should be extremely useful in supplying relevant and useful yardsticks to practitioners studying indoor air. It is the Committee's understanding that the overall shape and central portions ($25^{th}$ to $75^{th}$ percentiles) of these distributions are reasonably well defined and will provide much of the value of this study. The majority of the Committee was of the opinion that the Agency should direct a lesser, somewhat modest effort and level of attention to the tails of these distributions. They could be studied for the lessons they may hold. Indeed, these tails or "outliers" may represent a fundamentally different population and this could be important information. A reasonable level of sensitivity analysis could be conducted to provide more information and insight relative to these tails. There was a minority opinion that the Agency could lose significant information on subpopulations if it does not analyze the tails of the distributions.

b) *Ventilation Rate* - The Committee recommends that the Agency calculate the ventilation rates rather than have numerous users of the database repeat the exercise and possibly make mistakes. There may be some issues of relevancy with regard to the ventilation rate calculations and their association with occupant symptoms. Clearly the "core" zones receive less fresh air than "perimeter" zones but the anonymity of the survey data may prevent the placement of these occupants in either zone type. Also, the critical details of the treatment of infiltration and the issue of whether the representative area was in a "core" or "perimeter" area should be sorted out.

The Committee anticipates that there will be significant uncertainties in the ventilation rate calculations and recommends that these uncertainties should be clearly stated. The issues and problems associated with using $CO_2$ as a surrogate for ventilation rate are well established and should be a well-documented caveat in the reports that will describe the BASE data. In those situations where it is possible, both comparisons between $CO_2$-derived ventilation rates and the actual air flows measured in buildings and comparisons between ventilation rates calculated using the $CO_2$ approach versus the temperature approach would be useful. As an aside for future consideration, one IHEC Member has suggested the possibility of using an incidental outdoor air contaminant as a tracer penetrating within the building to directly measure infiltration. Possible outdoor air contaminants that would serve this purpose, and not usually found indoors (as in BASE) buildings are: the aliphatic hydrocarbons and some of the chlorinated hydrocarbons (e.g., trichloroethylene). Trace metals have also been used for this purpose.

c) *Associations* - As mentioned previously, the Committee agreed with the Agency's placement of the analyses of the associations and indices toward the bottom of the priority listing of analysis. Clearly, it will be most challenging to focus on the associations that have the greatest impact for public health; that is, those areas with the greatest practical significance. They are worthy and relevant projects but should only be implemented with the best in managerial and statistical acumen to first assign the level of acceptable power before it tests for associations.

If reasonably well-documented and adequately powered associations are established between symptoms, environmental parameters and building and HVAC characteristics then such calculations could be useful in determining good IAQ practices. These can then be publicized to help building owners improve their IAQ practices and help EPA achieve their GPRA goal of having 5% of the office buildings managed with good IAQ practices by 2005. Some potential associations to include in the analyses are:

1) water damage vs. biological contamination as an indicator of biologicals;

2) biologicals vs. asthma incidence (and biologicals vs. other symptoms);

3) type of filtration vs. $PM_{2.5}$ and type of filtration vs. $PM_{10}$; and

4) indoor volatile organic compounds (VOC) levels vs. ventilation rate.

As mentioned above, the appropriate and meaningful analyses of the associations will be very challenging given the uncertainties and other limitations of the data. The Committee commends the EPA for sharing the data set and exploring the possible associations with individuals outside the Agency.

### 3.5 Charge Question 4: Similar Analyses for Guidance in BASE Data Analyses

*Are there similar analyses (that have been conducted on other data sets) that EPA should use as guidance in its data analysis efforts?*

There are many similar analyses that have been conducted on other data sets, essentially too numerous to list (including several studies described in the proceedings for Indoor Air & Healthy Buildings). The IHEC acknowledges that the EPA personnel associated with the BASE study are well aware of most of this literature and cites four studies with analyses that may be particularly useful as guidance to the EPA for its data analyses. Those studies are: the California Healthy Building Study, the European Audit Project to Optimize Indoor Air Quality and Energy Consumption in Office Buildings, the Japanese Office Building Survey and the TEAM study.

a) *The California Healthy Building Study* - The California study included investigations on the relationships between the type of ventilation system, VOC levels, and office worker symptoms in 12 office buildings in the San Francisco Bay Area (Mendell, 1996). Using data from this study, Ten Brinke, Daisey and co-workers from the Lawrence Berkeley National Laboratory tested seven VOC exposure metrics in terms of their ability to predict complaints among office workers (Ten Brinke, et.al, 1998). Although some of the metrics were not statistically significant predictors of symptoms, the analysis of the data resulted in at least one statistically significant predictor of symptoms. The BASE study may lend itself to a similar examination.

b) *The European Project* - The European project compared IAQ parameters across different countries using 56 office buildings in 9 European countries (Bluyssen, 1995). The Agency may find some of the analyses used in the European project useful for analyzing the regional differences of the IAQ core parameters included in the BASE study. However, in it's recommendations on

the prioritization of the data analyses, the IHEC placed analyses on the representativeness of the buildings at the bottom of the list of priorities. Also, the Committee urges that the Agency exercise caution in conducting such an analysis to insure that such regional differences in IAQ measurements and questionnaire data are not "averaged" out. The IHEC also recommends that the Agency indicate whether data is weighted or unweighted if at some point, regional weighted factors are developed and employed.

c) *The Japanese Study* - The Japanese study included 131 office buildings in four major cities. The proportion of buildings with indoor environmental measurements exceeding acceptable levels according to Japanese guidelines (e.g. 1200 ppm for $CO_2$, 10 ppm for CO, temperature within 17°C-28°C, relative humidity within 40-70%, etc.) were assessed (Building Management Education Foundation, 1988). There are no comparable IAQ guidelines in this country. However, once the frequency distributions of measured variables have been determined, it would be easy to assess the proportion of measurements exceeding certain levels (e.g., outdoor air standards or indoor levels recommended by other national or international organizations).

d) *The EPA Team Study* - Some of the analyses used in the latter stages of the TEAM study should be useful as guidance (and are probably being used for this purpose). The TEAM studies of volatile organic compounds in several U.S. cities and the Particle (PTEAM) studies in California were important in characterizing the normal ranges of residential indoor and personal air exposures for US populations (EPA, 1996; 1997). In the latter stages of the TEAM study, the VOC data were fitted to log-normal distributions. The fits were reasonably good and the approach provided a convenient way to summarize a large amount of data. A similar approach may be useful in summarizing selected environmental measurements in the BASE data set.

e) *Comparing Data Sets*- The buildings included in these European and Asian studies are, in many ways, quite different from the buildings in the BASE data set. These differences include design, construction materials, furnishings, and the types and manner of operation of the HVAC systems. Nonetheless, besides using the above-mentioned studies for guidance in the developing the analyses plans for BASE, using the European and Asian studies to compare the results with those from BASE could also generate some insight into the understanding of building problems. For example, the comparison of questionnaire data

between BASE study and the National Institute for Occupational Safety and Health (NIOSH) investigations of complaint buildings has revealed some factors associated with complaints in office buildings (Brightman, 1997). Also, the data from the various studies can be compared to outdoor air standards or recommended indoor levels by various national or international organizations. Any cross-study analysis should include information on indoor sources of exposure. Such data may provide insight on those parameters that account for differences in indoor air quality found across studies.

f) *Complementary Longitudinal Study* - Along with the BASE study, there is a complementary longitudinal study referred to as the Temporal Indoor Monitoring and Evaluation (TIME) study. (Fortmann, 1994; EPA, 1999). Conducted by the EPA's Office of Research and Development, the longitudinal study collected the same core parameters in a smaller number of buildings. However, unlike the BASE study, samples in the longitudinal study were taken over different seasons. A portion of the buildings were included in both studies to ensure comparability and to provide some information on the relationship between cross-sectional and longitudinal measurements. The TIME study has the potential, when coupled with the BASE study, to provide valuable information on the relationships between cross-sectional and longitudinal studies. Therefore, the Committee strongly encourages the Agency to review and compare results from both cross-sectional and longitudinal studies simultaneously to make sure that necessary and comparable analyses are carried out on the data of both studies.

g) *Study on Water Damaged Buildings* - Swedish researchers Jan Sundell and Carl-Gustof Bornehag have assembled a database that contains studies of water damaged buildings (Sundell, and Bornehag, 1998). The Committee recommends that the EPA investigators contact Sundell and Bornehag for guidance on examining associations between water damage and building complaints for consideration in the analysis of the BASE data set.

h) *Studies from other data sets* - Studies from other data sets, not necessarily building studies, are also relevant in terms of guidance for data analyses. The EPA should consider reevaluating non-detect values using some of the more recently described approaches, including simulations and Monte Carlo methods. The Agency should also identify outliers and decide on a consistent procedure for treating them. If there is co-linearity between contaminants or between

contaminants and HVAC characteristics, these should be considered before all parameters are included in multivariate analyses.

In examining potential associations, the EPA should also consider some of the associations that have been reported in other building studies. However, the EPA should be selective; it should first consider those potential associations with the largest practical significance. When multivariate and stratified analyses are performed, demographic and building risk factors might be included as covariates and/or effect modifiers. (Risk indices could be calculated for individuals and for buildings, as well as the other indices that have been mentioned.) This is especially important in looking at the relatively simple symptom categories in relation to environmental parameters and/or building/HVAC characteristics.

## 4. SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

In this report the IHEC has made a number of recommendations for the BASE data analyses plan:

a) The IHEC concurs with the Agency's placement of Quality Assurance/Quality Control as a first priority for the data analysis.

b) After Quality Assurance/Quality Control, the Agency should analyze the descriptive statistics, in-depth, to provide a baseline of information about the characteristics of indoor air in the 100 commercial and pubic buildings included in the study.

c) The baseline data containing the descriptive statistics should be released to the public as soon as the statistical analysis has been completed.

d) The BASE study should be integrated into the Agency's other efforts to analyze cumulative exposure in order to maximize the impact of BASE on the overall protection of pubic health.

e) Before testing for associations, the Agency must first assign the level of acceptable power before it tests for associations.

f) The EPA should incorporate guidelines regarding the scientific limitations in using the data to reduce the likelihood that the data are misinterpreted and that invalid associations are inferred and to reduce the likelihood of data dredging, especially given the large number of variables in the study.

g) The Agency should review and compare results from both the cross-sectional study (BASE) and the longitudinal study (TIME) simultaneously to make sure that necessary and comparable analyses are carried out on the data of both studies.

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* Material reviewed by the Committee prior to the meeting.

# APPENDIX A - ACRONYMS AND ABBREVIATIONS

| | | |
|---|---|---|
| BASE | - | Building Assessment Survey Evaluation |
| BSI | - | Building Symptoms Index |
| CFM | - | cubic feet per minute |
| CO | - | carbon monoxide |
| $CO_2$ | - | carbon dioxide |
| CV | - | constant volume |
| DOE | - | Department of Energy |
| GPRA | - | Government Performance and Results Act |
| HVAC | - | Heating, Ventilation and Air-Conditioning |
| IAQ | - | Indoor Air Quality |
| IHEC | - | Integrated Human Exposure Committee |
| NHANES | - | National Health and Human Nutrition Examination Survey |
| NHEXAS | - | National Human Exposure Assessment Survey |
| NIOSH | - | National Institute for Occupational Safety and Health |
| ORD | - | Office of Research and Development |
| PM | - | particulate matter |
| PTEAM | - | Particle Total Exposure Assessment Methodology |
| QA/QC | - | Quality Assurance/Quality Control |
| SAB | - | Science Advisory Board |
| TEAM | - | Total Exposure Assessment Methodology |
| TIME | - | Temporal Indoor Monitoring and Evaluation Study |
| VAV | - | variable air volume |
| VOCs | - | Volatile Organic Compounds |

# APPENDIX B - BASE Core Parameters

| BASE Core Parameters | | | |
|---|---|---|---|
| **Environmental Measures** | **Building Characteristics** | **HVAC Characteristics (A)** | **Occupant Questionnaire (5)** |
| **CONTINUOUS SAMPLING**<br>• Temperature (1)<br>• Relative Humidity (1)<br>• Carbon Dioxide (1)<br>• Sound (indoors only) (1)<br>• Light (indoors only) (1)<br>• Carbon Monoxide (1)<br>• Radon (indoors only) (2)<br>**INTEGRATED SAMPLING**<br>• Particles (3)<br>  S $PM_{10}$, $PM_{2.5}$<br>• VOCs (3)<br>• Formaldehyde (3)<br>• Bioaerosols (4)<br>  S air,<br>  S visible growth | • Use (W)<br>• Age (W)<br>• Floor Area (W)/(T)<br>• # of Floors (W)/(T)<br>• Occupancy (W)/(T)<br>• Geographical Location (W)<br>• Ventilation (W)<br>  S equipment<br>  S operation<br>  S schedule<br>• Construction (W)<br>• Outdoor Sources (W)<br>• Special Use Spaces (W)/(T)<br>• Smoking Policy (W)/(T)<br>• Water Damage (W)/(T)<br>• Fire Damage (W)/(T)<br>• Renovation (W)/(A)<br>• Pest Control (W)/(T)<br>• Cleaning Practices (W)/(T) | • Type<br>• Specifications<br>  S air handler<br>  S exhaust fans<br>• Filtration<br>• Air Cleaning Systems<br>• Air Washers<br>• Humidification Systems<br>• Maintenance Schedule<br>• Inspection Schedule<br>• Supply Air Flow Rate (6)<br>• Percent Outdoor Air (6)<br>• Outdoor Air Intake Rate (6)<br>• Supply Air<br>  S temperature (1)<br>  S relative humidity (1)<br>• Exhaust Fan Rates (6)<br>• Local Ventilation Performance (7)<br>• Natural Ventilation Measurements (if needed) | • Workplace Physical Information<br>• Health and Well-being<br>• Workplace Environmental Conditions<br>• Job Characteristics |

(1) Tuesday AM to Thursday PM (5 min. averages)
(2) Monday PM to Thursday PM
(3) 8-9 hrs on Wednesday
(4) 2 min. and 5 min. sampling twice (AM and PM) on Wednesday
(5) Distributed Thursday AM. Collected until Thursday PM and Friday AM.
(6) Tuesday AM, Wednesday and Thursday AM and PM
(7) Tuesday PM
(W) Whole building information
(T) Test space information
(A) Information for total area served by air handling units serving study space

Prepared by the USEPA, Office of Air and Radiation, Office of Radiation and Indoor Air, Indoor Environments Division

# APPENDIX C - Proposed BASE Analyses

| Analysis* | Item/Description |
|---|---|
| Quality Assurance/Quality Control | - Review for errors, needed changes, or missing data points |
| | - Determine accuracy and precision |
| Representativeness of Building Samples/Weighting Determinations | - Compare regional frequency distribution of building characteristics (occupancy, gross floor area, building age, # of floors) to DOE |
| | - Examine any potential biases resulting from building selection process |
| | - Develop regional weighing factors to use in developing nationally representative distributions |
| Ventilation Rate Calculations-% outdoor air, air exchange rate and CFM/occupant | - Tracer gas (continuous $CO_2$ in outside air, supply, return, and occupied space) |
| | - Temperature differences (outside air, supply, return, and occupied space) |
| Frequency Distribution (normative data) | - Concentration |
| | - Symptoms |
| | - Comfort parameters (continuous temperature and relative humidity, sound and light) |
| | - Building and HVAC characteristics |
| | - Building maintenance practices |
| | - Sources (furnishings, special use, copiers, computers, smoking, cleaning materials, pesticides...) |
| | - Occupant demographics |
| Associations | - Symptoms |
| | - Environmental parameters |
| | - Building and HVAC characteristics |
| Develop Indices and Measures | - Building symptom indices |
| | - Indoor pollutant indices |
| | - Building system quality indices |

*Prior to the SAB review, the Agency planned to study the items in the first column in the order in which they appear.

This table was originally prepared by USEPA Office of Air and Radiation, Office of Radiation and Indoor Air, Indoor Environments Division.

# APPENDIX D - GPRA Strategic Goal 4, Objective 4

By 2005, 15 million more Americans will live or work in homes, schools, or office buildings with healthier indoor air than in 1994.

More specifically, to reduce lung cancer, respiratory diseases, and other health problems, 11.5 million more Americans will be exposed to healthier indoor air in their homes by the mitigation of 700,000 homes with high radon levels, the construction of one million homes with radon-resistant construction techniques, a reduction in the proportion of households in which children 6 and under are regularly exposed to smoking from 27% in 1994 to 15%, and a reduction in the number of children and low-income populations exposed to indoor air pollutants which worsen or trigger asthma episodes. To reduce health problems in the nearly 10 million children made ill annually from indoor air problems in schools, 15% of the nation's schools will adopt good IAQ practices consistent with EPA's "Tools for Schools" guidance. To reduce IAQ-related illness from contaminated air in the workplace, 5% of office buildings will be managed with good IAQ practices consistent with EPA's "Building Air Quality" guidance.

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