Presented at Healthy Buildings '95, September 11-14, 1995.

# Developing Baseline Information on Buildings and Indoor Air Quality (BASE '94): Part I -Study Design, Building Selection, and Building Descriptions

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## INTRODUCTION

The U.S. EPA's Office of Radiation and Indoor Air (ORIA) has initiated a major study of indoor air quality (IAQ) to fill a significant data gap that exists regarding baseline IAQ in public and commercial office buildings. The goal of the study is to define the status of the existing building stock with respect to IAQ and occupant perceptions. The on-going cross-sectional study, entitled Building Assessment Survey and Evaluation (BASE) Program, is collecting baseline data characterizing public and commercial office buildings. The study buildings are randomly selected without regard to IAQ complaints. Core parameters are measured in a representative space in each building. This paper discusses the study design and the building and study space selection. Summaries of building descriptions and the results of measurements related to thermal comfort and ventilation for the first thirteen buildings are also included. The building descriptions include information about building age; size; study area location within the building; heating, air-conditioning and ventilation (HVAC) system type; occupant activities; smoking policy; and percent outdoor air. The measurements related to thermal comfort include indoor and outdoor temperatures and relative humidities. The data collected are coded for confidentiality and are in a publicly-accessible database. A separate paper (Part II) presents the results of pollutant measurements and occupant perceptions.

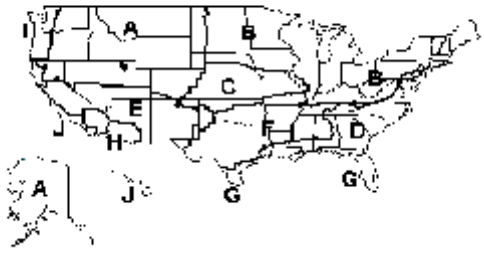
## STUDY DESIGN

The "Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings,"[1] used in the BASE program to collect uniform baseline information on IAQ in public and commercial office buildings, is a result of discussions with over 40 IAQ experts from the USA. The experts were convened to provide information on program development in the following areas: study design; building and HVAC characteristics; human response and questionnaires; environmental measurements; program integration; and diagnostics and mitigation. The experts were asked to identify the key parameters that should be measured, at a minimum by any indoor air researchers, to characterize the indoor environment in large buildings. The study is not hypotheses driven and it will not necessarily produce the type of diagnostic data needed to evaluate the nature, validity, or cause of IAQ complaints. Rather, the data collected in these studies are expected to provide a distribution of IAQ building/HVAC characteristics; obtain baseline symptom rates; establish standardized testing protocols; examine relationships of symptoms to building characteristics; develop hypotheses to investigate sick building syndrome; and provide the basis for guidance on building design, construction, operation and maintenance of buildings. In order for data to be as representative as possible, buildings are randomly selected from ten different climatic regions across the country. The buildings are characterized, in either the summer or winter months, using the standard protocol. Specific core parameters are measured in a representative sampling space within each building. These core parameters include environmental measurements, an occupant questionnaire, and characterization of the HVAC system and the building itself.

Over the course of three to five years, the BASE program plans to survey between 100 to 200 buildings. Although buildings are not chosen on the basis of IAQ complaints, it is expected that the random selection process will result in the inclusion of some complaint buildings in the study. The only basis for exclusion from the study is if the office building does not meet the occupancy and ventilation requirements, or if the building has been highly publicized as a "sick" or "problem" building.

The BASE building selection is based upon only one stratification, that due to the climate. Using values from the American Society of Heating, Refrigeration, and Air Conditioning Engineers' (ASHRAE) table[2] which specifies engineering design conditions for the summer 2.5% and winter 97.5% dry-bulb temperatures, the country was divided into 10 climatic regions (see Figure 1).

Figure 1 - BASE REGIONS MAP




Cities of over 100,000 population were identified in each region which have similar heating and cooling requirements. Table 1 lists the regions

defined by these design criteria and shows that the criteria for Regions D, G, H, I and J overlap. The Pacific Northwest, the California coast, and the Gulf of Mexico coast were judged to be sufficiently different in terms of building design, construction and operation that they were broken into separate regions. If, after the data are collected, it appears that some of the regions should be combined, this can occur without compromising the study.

Using these designated regions and selecting from cities of over 100,000 population, a city is randomly chosen using a random number generator. Buildings are chosen within that selected city by using commercially available listings of business addresses. Calls are made to businesses by randomly sampling the zip codes, streets, and addresses; making calls to the business listings; asking if they are located in an office building, and if so, asking who is the building owner/manager. The building owner/manager is then contacted and asked whether

**TABLE 1**: Region Definition

| | | Summer Design condition (2.5% design dry bulb) | | | |
|---|---|---|---|---|---|
| | | Dew Point $< 53^0$ | | Dew Point $\geq 53^0$ | |
| | | Temp $<94^0$ (cool/mod) | Temp $\geq 94^0$ (hot) | Temp $< 94^0$ (cool/mod) | Temp $\geq 94^0$ (hot) |
| Winter | cool $\leq 10^0$ | A | A | B | C |
| Design | mod. $11^0$ - $32^0$ | D | E | D or I | F |
| Temperature | hot $> 32^0$ | G | H | G or J | G or H |

they would allow the study to be conducted in their building. Many of the business establishments contacted are not eligible since they include all types of establishments (e.g., pizza parlors and beauty salons). Once it is determined that the building has a sufficient number of occupants and is willing to participate, preliminary visits are scheduled to confirm the suitability of the building for inclusion in the study.

The test space within a building is defined based upon an occupancy of at least 50 full-time employees who can be given the questionnaire, served by a maximum of two air handling units, and residing on no more than three floors. General information is collected regarding the building itself, such as the age, construction features, use, furnishings, renovations, local point sources, and general maintenance. The HVAC system is characterized regarding its maintenance, design features, and the amount and quality of fresh air being introduced into the building and, more specifically, the test space. Environmental measurements include comfort parameters such as light, sound, temperature, and relative humidity as well as pollutant concentrations. A list of the core measurements is found in Table 2.

The protocol also specifies the schedule of measurements, the specifications of the measurement equipment, how to randomly select the representative space and sampling sites within that space. An *Indoor Air Data Collection System (IADCS)* software program has been developed to collect data in the field in a consistent manner and for ease of entry into the EPA central

database. An EPA Quality Assurance Overview Document[3] has also been developed which specifies the accuracy and precision needed for the data to be acceptable for inclusion in the database. The plan is designed to address issues associated with conducting large building surveys, and provides the framework for the quality assurance plan.

The protocol is designed to be conducted in two parts. A visit to the building before the week of sampling is necessary to explain the study to the building management, to determine if there are suitable testing zones within the building, and to conduct a preliminary examination of the HVAC system. Selected building checklists contained in the protocol and IADCS are completed during this preliminary visit. During the actual week of sampling, environmental measurements are collected at three or more sites within the representative sampling zone and at one outdoor site. Subjective observations regarding odor, housekeeping, and pollutant point sources are made at a minimum of five indoor sites twice a day on both Wednesday and Thursday. Continuous measurements of carbon dioxide, carbon monoxide, temperature, relative humidity are made at the three indoor and the outdoor site beginning Tuesday afternoon and continuing until Thursday evening. Measurements of light and sound are also made continuously at three indoor sites. Integrated samples for volatile organic

**Table 2**: BASE Core Parameters

| Environmental Measurements | Building Checklist | HVAC Checklist | Occupant Questionnaire |
|---|---|---|---|
| Temperature | Use | Type | Workplace Physical Information |
| Relative Humidity | Occupancy | Specifications (air handler, exhaust fans) | |
| Carbon Dioxide | Geographical Location | Filtration | Health and Well-being |
| Sound | Ventilation (equipment, operation schedule) | Air Cleaning Systems | |
| Light | Construction | Air Washers | Workplace Environmental Conditions |
| Carbon Monoxide | Outdoor Sources | Humidification Systems | |
| Particles ($PM_{10}$, $PM_{2.5}$) | Smoking Policy | Maintenance Schedule | |
| VOCs | Water Damage | Inspection Schedule | Job Characteristics |
| Formaldehyde | Fire Damage | Supply Air Flow Rate | |
| Bioaerosols (air, visible growth) | Renovation | Percent Outdoor Air | |
| Radon | Pest Control | Outdoor Air Intake Rate | |
| | Cleaning Practices | Supply Air (temperature, relative humidity) | |
| | | Exhaust Fan Rates | |
| | | Local Ventilation Performance | |
| | | Natural Ventilation Measurements (if needed) | |

chemicals (VOCs), formaldehyde, and $PM_{10}$, are collected at the three indoor sites and the outdoor site over a nominal eight-hour period on Wednesday. Bioaerosol samples (bacteria, fungi, and thermophile) are collected Wednesday morning and afternoon at the three indoor sites and the outdoor site. $PM_{2.5}$ is collected at one indoor and the outdoor site Wednesday.
Radon samplers are distributed on the ground contact floor, elevator shaft and stairway entrances in the sampling zone and at three sampling sites in the zone. Air flow measurements are made Tuesday afternoon at the test space primary air supply and at all the diffusers in the sampling zone. On Wednesday and Thursday, the HVAC measurements parallel the environmental measurements and include, in addition to air flow, measurements of the temperature, relative humidity, and carbon dioxide in all the supply and return air ducts serving the sampling zone.

The questionnaire is given individually to all occupants in the sampling zone on Thursday of the sampling week, with steps taken to maintain strict confidentiality. The questionnaires are to be returned Thursday afternoon, which allows for any follow-up collection Friday.

## RESULTS

During the 1994 BASE study, calls to 1648 different tenants resulted in the identification of 138 building owners and managers. Of those 138, 43 were contacted to determine if their building had sufficient occupancy to be eligible for the study. Thirty-nine of the buildings were determined to be eligible and 22 owners/managers (56%) expressed an interest in participating in the study. Preliminary visits were made to all 22 buildings and two buildings were eliminated because they did not meet the ventilation system criterion. Buildings were randomly selected from those eligible in each city and 13 were surveyed. Table 3 contains summary building data for the first 13 BASE buildings. Temperature measurements were made at four levels to determine if stratification was occurring, but only temperatures at 1.1 meters above the floor are reported in this report. Relative humidity was measured directly indoors. Outdoors, dew point was measured and converted to relative humidity. The building mean and range for these data are shown in Table 4.

## SUMMARY

This paper presents the goals, study design, and building selection scheme for developing baseline information on IAQ and occupant perceptions in office buildings. The data collected in these studies is an important first step in providing information on the distribution of building and HVAC characteristics, temperature and relative humidity, and outdoor air ventilation rates for randomly selected buildings in the U.S. In addition, the standardized protocol developed for BASE allows the establishment of an extensive data base, comprised of uniformly collected data, as a resource for researchers and policy makers. The data have the potential to provide the basis for guidance on building design, construction, operation and maintenance of buildings.

**TABLE 3:** Data regarding building age, size, study area location, smoking policy, ventilation type, and percent outdoor air are shown for the first 13 BASE buildings.

| Building ID[1] | Age | Building Envel-ope | Gross Area ($m^2$) | No. of Floors | Floor(s) of Study Area | No. of Occu-pants | Smoking policy | Venti-lation Type | ACH[2] ($h^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| MNBW01 | 7 | Masonry | 37,900 | 37 | 9 | 1130 | NSC[3]/S[4] | VAV | 0.2 |
| MNBW02 | 90 | Masonry | 12,100 | 7 | 7,8 | 400 | NS[5]/NE[6] | VAV | 0.8 |
| MNBW04 | 18 | Brick | 3,400 | 4 | 2,3,4 | 67 | S | VAV | -[8] |
| CAJS01 | 100 | Brick | 14,000 | 17 | 7,8,9 | 250 | NS/NE | CAV | 2.0 |
| CAJS02 | 41 | Concrete | 47,000 | 8 | 5 | 850 | NS | CAV | 2.5 |
| CAJS03 | 29 | Brick | 11,700 | 18 | 6,7,8 | 180 | NS | CAV | 0.1[9] |
| MOCS01 | 6 | Glass/ Metal | 28,300 | 6 | 6 | 630 | NS/SL[7] | VAV | 0.8 |
| MOCS05 | 21 | Glass/ Metal | 9,700 | 11 | 7,8 | 300 | NSC/S | VAV | 0.7 |
| ORIS02 | 99 | Brick | 7,400 | 3 | 2,3 | 108 | NSC | Natural | 0.1[9] |
| ORIS03 | 29 | Concrete | 7,200 | 5 | 2 | 250 | NS/NE | CAV | 1.0 |
| ORIS04 | 80 | Brick | 26,000 | 8 | 3 | 610 | NS | CAV | 1.7 |
| TXFS01 | 4 | Glass | 106,700 | 4 | 2 | 1300 | NS | VAV | 0.2 |
| TXFS02 | 12 | Masonry | 2,800 | 2 | 1,2 | 87 | NS | VAV | 0.2[9] |

[1]The buildings are identified with a unique code as follows: the first two letters represent the postal abbreviation for the State (e.g., MN represents Minnesota); the third letter represents the climatic region for the BASE study; the fourth letter designates a building studied in winter (W) or summer (S); and the two digits are a building designation for the study.

[2] Estimated air exchange rate using carbon dioxide mass balance.

[3] Non-smoking common areas

[4] Smoking

[5] Non-smoking

[6] Non-smoking, not enforced

[7] Smoking lounge

[8] Data not available

[9] The outdoor carbon dioxide level was estimated to be 350 parts per million

**TABLE 4**: Temperature and relative humidity values for the first 13 BASE buildings

| Building ID | Temperature | ($^{o}$C) | Relative Humidity | (%) |
|---|---|---|---|---|
| | Indoor Mean (Min-Max) | Outdoor Mean (Min-Max) | Indoor Mean (Min-Max) | Outdoor Mean (Min-Max) |
| MNBW01 | 21.2 (16.7 - 23.9) | 4.3 (-4.6 - 14.1) | 16.3 (12.5 - 21.4) | 12.8 (12.6 - 29.8) |
| MNBW02 | 21.0 (18.1 - 29.7) | 1.9 (-4.2 - 20.5) | 16.4 (11.6 - 79.6) | 69.9 (20.8 - 96.3) |
| MNBW04 | 21.9 (19.0 - 27.4) | 2.7 (-4.1 - 20.5) | 10.8 (7.3 - 17.3) | 53.4 (31.5 - 85.5) |
| CAJS01 | 21.1 (18.0 - 26.5) | 14.8 (13.1 - 17.6) | 53.9 (45.7 - 61.8) | 74.1 (60.0 - 84.4) |
| CAJS02 | 23.1 (21.4 - 24.3) | 13.7 (11.6 - 17.3) | 43.4 (36.6 - 47.8) | 69.4 (58.7 - 78.9) |
| CAJS03 | 23.4 (20.8 - 27.0) | 18.0 (12.8 - 23.2) | 49.6 (45.2 - 56.7) | 62.6 (46.3 - 80.0) |
| MOCS01 | 22.1 (19.1 - 29.5) | 26.1 (21.4 - 32.8) | 38.7 (33.1 - 44.6) | 60.5 (37.4 - 79.0) |
| MOCS05 | 23.0 (19.2 - 27.6) | 26.6 (18.7- 32.7) | 46.3 (38.1 - 55.3) | 59.5 (38.8 - 71.0) |
| ORIS02 | 23.2 (17.0 - 28.3) | 20.7 (12.7 - 30.8) | 37.9 (27.9 - 46.4) | 48.0 (25.9 - 68.1) |
| ORIS03 | 24.0 (22.5 - 25.8) | 20.4 (14.2 - 26.9) | 42.8 (39.4 - 47.7) | 54.8 (32.8 - 74.8) |
| ORIS04 | 22.5 (19.5 - 24.8) | 20.8 (16.0 - 25.3) | 47.7 (42.5 - 54.5) | 47.8 (32.3 - 61.9) |
| TXFS01 | 23.5 (19.7 - 26.5) | 29.7 (21.6 - 36.2) | 43.7 (40.0 - 49.2) | 62.0 (41.6 - 85.2) |
| TXFS02 | 23.3 (20.0 - 26.2) | 29.5 (23.2 - 37.2) | 54.2 (47.7 - 65.7) | 65.5 (39.8 - 93.8) |

## REFERENCES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2. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Chapter 26, Table 1 Climatic Conditions for the United States, in :"1989 ASHRAE Handbook Fundamentals,"American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA, 1989.

3. U.S. Environmental Protection Agency, "A Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings," Office of Research and Development and Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, USA, June 1, 1994.