TEXAS ELEMENTARY SCHOOL INDOOR AIR STUDY (TESIAS): OVERVIEW AND MAJOR FINDINGS

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ABSTRACT
A study of 120 randomly selected classrooms in 30 schools in central and south Texas, USA was conducted to begin assembling baseline information on the condition of indoor air in Texas elementary schools. Part I of the study consisted of questionnaires sent to all teachers and staff in the schools to obtain information about the use of their rooms, room contents and their perceptions of its indoor air quality. Part II consisted of walkthroughs in each school and the 120 classrooms to obtain information on the building design, HVAC system and condition of the space/building. It also included making measurements of temperature, relative humidity, carbon dioxide, and carbon monoxide in the selected classrooms. Additionally, air samples were analyzed for fungal and bacterial genera, counts of airborne particles, and volatile organic compound levels in 18 classrooms.

INDEX TERMS
Elementary school, Indoor air study, Microbial contaminants

INTRODUCTION
The U.S. General Accounting Office (1995) has estimated that at least one in five U.S. schools has significant indoor air quality problems. The purpose of the Texas Elementary School Indoor Air Study (TESIAS) was to begin to develop benchmark information related to the condition of indoor air in Texas elementary (K–6) schools. The project consisted of three main tasks. Phase 1 consisted of a survey of health symptoms and perceptions of indoor air quality of occupants at 30 schools in central and south Texas. Phase 2 consisted of two tasks. Task 1 was a walkthrough of the 30 elementary schools and measurement of comfort parameters in 120 randomly selected classrooms in these schools. Task 2 consisted of a comprehensive investigation of indoor air parameters in a subset of 18 classrooms from these schools.

APPROACH
The primary objective of this project was to identify and begin to assemble relevant information about the condition of indoor air in Texas elementary schools. To do this, we first selected schools in geographical areas representative of typical climate regions in Texas. Texas schools are located in three hygro-thermal climate regions (Lstiburek, 2001): hot-dry/mixed-dry, hot-humid, and mixed-humid. Funds and the period of funding for the project allowed the selection of schools from a maximum of two of these climate regions. The two regions selected were hot-humid and mixed-humid. Major public school districts in these

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regions were approached to participate in the project. A school district in central Texas and one in the Rio Grande Valley of south Texas were selected for participation in the study.

Prior to approaching the school districts, the data that were deemed necessary to characterize the condition of indoor air in a classroom were identified. Project funds and school routines restricted the nature and extent of data that could be selected. Considerable attention was given to selecting information that would be the most useful. Once these data were identified a two-phase approach was developed to obtain the data. First, a questionnaire to obtain information from building occupants about their rooms, its use and contents, and their perceptions of the indoor air quality was designed, distributed, collected, and analyzed. The types of information requested in the questionnaire were also designed for comparison with field data that were gathered in the second phase of the study. The second phase involved a walkthrough of each school and the selected classrooms, as well as measurements of typical indoor air quality parameters. The latter was done in two phases. The first was a screening phase of all 120 classrooms that included measurements of comfort parameters (temperature, relative humidity, carbon dioxide, and carbon monoxide) and visual inspections to record the physical design and condition of the room. The second phase included only 18 classrooms, within which measurements were made to characterize the same parameters as the screening phase plus three additional parameters: biocontaminant activity, particulate matter and volatile organic compounds (VOCs). These two phases were conducted at separate times. Once information from the first phase was analyzed, it was used to rank order the 120 classrooms according to the room and indoor air conditions. The 18 classrooms for the second phase were selected to be representative of the percentage and variation in the condition of the 120 classrooms.

METHODS

The design and scope of the experimental program were, in part, a function of budgetary limitations and time considerations. The program included a distribution of staff questionnaires, walkthrough surveys of the school grounds, individual classrooms and HVAC systems, as well as monitoring of temperature, relative humidity, carbon dioxide, carbon monoxide, bacteria, total aerosolized fungi, viable aerosolized fungi, total surface fungi, viable surface fungi, airborne particle counts, and VOCs.

Selection of Schools & Classrooms

Schools and classrooms were selected from two participating Texas school districts, hereafter referred to as B and G, located along the US-Mexico border and central Texas, respectively. Budgetary constraints dictated that 30 schools be selected for Phase I. Of those selected, 20 schools were selected from district G due to the close proximity to The University of Texas at Austin. In addition, elementary schools within district G represent a disproportionately larger number of elementary schools within a wider range of socioeconomic regions. Within district G, two schools were randomly selected from each of ten “maintenance zones” from a total of 74 elementary schools. Within district B, 10 schools were randomly selected from a total of 21 elementary schools. Eight classrooms were randomly selected from each school for Phase I. A total of eighteen classrooms (from both districts) were monitored during Phase II. These classrooms were selected utilizing a matrix designed to evaluate the condition of the classrooms as indicated by Phase I data. Classrooms were then randomly selected from each of the nine numerical ranges between the highest and lowest matrix values.

Questionnaires

Questionnaires (Qx) were distributed to all administrators, teachers, teacher aides, and staff for each school selected for Phase I. The questionnaire was designed to fit on a one-page (front and back) scantron sheet to improve the likelihood of response. The Qx was designed to consume no more than 10 minutes of staff time to complete, and was divided into five main sections. The first section, Respondent Information, asked for general information about the respondent such as age range, gender, job category, years at present school, and total years in K-12. The second section, General Room Information, queried for information about the type of space, if it was a portable building, and typical number of students occupying the space. Section 3, Information Specific to Your Work Room, asked the respondent to provide information about the type and condition of the finish materials, room contents, maintenance history, water leaks, pets, renovations, air freshener and candle usage, and pesticides usage. The fourth section, Observations and Perceived Quality, asked the respondent to indicate the frequency of several common odors as well as characterize the overall quality of the room environment. Finally, Section 5: General Health Symptoms asked the respondent to indicate the frequency of several common symptoms associated with indoor environmental issues (as well as some not typically associated with indoor environments). In addition, the respondent was asked to determine which, if any, symptoms occur more frequently at home than at work as well as which symptoms have affected students most during the past month. Approximately 1400 questionnaires were analyzed, 900 from teachers.

Walk-Through Surveys

Three walk-through surveys were utilized during Phase I to document the materials, design, condition and cleanliness of the school grounds, classrooms, and the HVAC system for each classroom selected.

The walkthrough form for school grounds was used to gather general information about each of the thirty schools selected for Phase I. Information gathered included but was not limited to the age, levels, renovations, portable buildings, common area finish materials, lighting, barrier mats, cleanliness, maintenance closet chemical storage and ventilation, soil erosion, site drainage, gutters and downspouts.

The classroom walkthrough form was used for each of the eight classrooms per school selected for Phase I. The form was used to gather information about the finish materials and their condition for floors, walls and ceilings. In addition, operable exterior doors and windows were identified on exterior walls. The presence of classroom contents such as chalkboards, copiers, fans, computers, plants, pets, etc. were also noted. Information about environmental modifiers including air fresheners, candles, incense, and pesticides were also collected. Finally, data were collected as “spot checks” for comfort parameters (temperature, humidity, CO_2) as well as general environment issues such as odors, lighting levels, and cleanliness.

The HVAC walk-through form was also used for each of the eight classrooms per school selected for Phase I. The form was used to gather information about the system type, outside air, system controls, filters, coils, machine room, and the ducts. Information was gathered about the design, operation, maintenance and cleanliness of the HVAC systems for each classroom.

Phase I Monitoring
Monitoring in Phase I was performed on four randomly selected (of the 8 that were already selected) classrooms from each school. Phase I monitoring was limited to temperature, relative humidity and CO_2, all of which was measured and logged using the same instrument. Two separate instruments were also used to detect and log CO concentrations. Units were placed in classrooms in the morning before arrival of students and removed a minimum of thirty minutes after student dismissal at the end of the school day. Spot checks were performed with a fifth instrument to measure the outside levels in both the morning and afternoon, and inside levels during walkthroughs.

Phase II Monitoring
The second phase of monitoring occurred in Spring and was of much greater intensity than the previous phase. A total of 18 classrooms were selected for Phase II from the approximately 120 classrooms monitored in Phase I. These classrooms were continuously monitored for carbon dioxide, carbon monoxide, temperature and humidity. In addition, each classroom was also sampled for microbes, particle counts and size analysis, and total and speciated VOCs. Microbial sampling was performed in the morning prior to occupancy and once during an occupied time of the day. Identical bioaerosol sampling was performed during both the occupied and unoccupied times. This sampling included one total fungal sample collected by impaction cassette and a hand-held pump. Samples were collected for 10 minutes at a flow rate of 15 L/min. Viable fungal and bacteria samples were collected on malt extract agar and blood agar culture plates, respectively. Samples were collected using a single-stage impactor and a high volume pump for 4 minutes at a flow rate of 28.3 L/min. In addition to bioaerosols, two surface samples of each type were collected using a tape lift and swab in each classroom. One of each surface sample type was collected for a vertical and horizontal surface. Samples were also collected of any visual contamination suspected within the room. For comparison, outdoor bioaerosol samples of total fungi, viable fungi, and viable bacteria were collected in both the morning and afternoon. In addition, duplicate samples, field blank samples and two separate commercial labs were utilized for quality control purposes.

Volatile organic compound (VOC) samples were collected once in each classroom, with simultaneous outdoor sampling. Samples were collected using a personal sampling pump and glass cartridges packed with Tenax-TA. They were analyzed by a commercial laboratory using large volume thermal desorption/GC/MS. Unfortunately, sample preservation and analysis procedures were determined to violate the quality assurance project plan. As such, the authors have confidence in chemical speciation (identification) but are reluctant to release speciated concentrations at this time. In this paper we have opted to describe only the most common VOCs identified in these classroom environments.

Fine particle counts and mass concentrations in both indoor and outdoor air were collected using two separate laser-based particle analyzers, one for size-selective particle count concentrations over eight size ranges (0.1-0.2 μm minimum) and one for determination of $PM_{2.5}$ mass concentration. Samples were collected for short periods (15 to 20 minutes) before and after classroom occupation. The latter were collected at least one hour after students and teaching staff had entered the classroom.

Database
All of the data and information collected from the questionnaires, walk-through forms, and Phase I and Phase II monitoring events were entered into a single database to allow for queries of varying parameters. The database has just recently been completed, and intensive data mining will continue well into 2002.

RESULTS
Preliminary analysis of the questionnaires yielded some interesting insight into the profile of respondents and their perception of their indoor environments. Of the respondents, the majority were teachers (67%) and teachers' aides (14%). The remaining 19% of respondents was composed of office staff, administration, cafeteria staff, and custodial staff. An example of the types of information gained from the questionnaire results involves issues related to odors and odor masking. For this study, 45% of teachers and 55% of students were bothered by odors in the classroom. Thirty percent of teachers indicated that they use spray air fresheners, 19% use plug-in air fresheners, and 8% use scented candles. Also of interest, teachers indicated that 37% of the classrooms had water leakage and 19% indicated they used pesticides in the classroom.

At the time of this writing, bioaerosol concentration data have been analyzed for district G only. Selected data are presented herein. For total viable fungi concentrations (cfu/m^3), three genera of fungi were found to exceed their outdoor rank order contribution more frequently than any others. They were *Penicillium sp*. (33% during unoccupied periods/ 29% during occupied), *Alternaria sp*. (33% during unoccupied periods/ 17% during occupied), and *Epicoccum sp* (21% during unoccupied periods/ 17% during occupied). Occupied viable fungi concentrations ranged from 71 cfu/m^3 to 717 cfu/m^3, with a median value of 390 cfu/m^3. Unoccupied viable fungi concentrations ranged from 36 cfu/m^3 to 576 cfu/m^3, with a median value of 258 cfu/m^3.

The following information regarding VOCs is presented given the caveats described in the Phase II Monitoring section of this paper. There were six VOCs that were identified in 80% or more of the 18 classrooms that were sampled. In all cases, these six VOCs appeared to exist at much higher concentrations indoors than outdoors: decane, dodecane, 1,4-dichlorobenzene, d-limonene, nonanal, and trimethylbenzene (all isomers). In addition, the following seven VOCs were observed in 50 to 79% of classrooms: decanal/naphthalene (could not be resolved analytically), ethyl methyl benzene, heptanal, methyl isobutyl ketone (MIBK), octanal, phenol, and m,p-xylene. The total VOC concentrations in classrooms were as high as 1,400 μg/m^3, with a mean value of 230 μg/m^3. However, these are likely lower-bound values due to poor sample recovery and it would be more appropriate to state each as "greater than" the values shown.

Indoor fine particulate matter ($PM_{2.5}$) concentrations varied between 11 and 66 μg/m^3 over all 18 classrooms, with an arithmetic mean value of 30 μg/m^3 and a standard deviation of 17 μg/m^3. In every classroom, the ambient $PM_{2.5}$ concentration exceeded the pre-occupation $PM_{2.5}$ with an average I/O ratio of 0.33. In 16 of 18 classrooms, the ambient $PM_{2.5}$ concentration exceeded the post-occupation $PM_{2.5}$ with an average I/O ratio of 0.50. Total particle counts (for sizes less than 2 μm) ranged from 2 x 10^5/L to 2 x 10^6/L, with particles less than 0.3 μm dominating the count contribution (>94% of total particle count). In general, pre-occupation particle counts were greater than post-occupation counts for particles less than 0.4 μm and less than post-occupation counts for particles greater than 0.4 μm. Ambient particle counts were consistently greater than indoor particle counts, suggesting that they are a major contributor to indoor particles, with potential for significant entry during the morning arrival of students.

DISCUSSION

The bioaerosol and VOC results in some classrooms provide indications of potential IAQ problems that warrant further investigation. Unfortunately, this study did not allow the opportunity to conduct these additional investigations. Occupant perceptions of the quality of the air in these classrooms and CO_2 concentration in these classrooms (presented in a companion paper) tend to support the theory that serious IAQ problems may exist in some classrooms. These data begin to provide a range of typical pollutant concentrations that exist in elementary school classrooms, and insights regarding the sources of these problems.

CONCLUSION AND IMPLICATIONS

There are many factors that can affect the quality of the indoor air in any building, especially schools. The TESIAS is attempting to identify the parameters best suited to compare the condition of the indoor air in one classroom to that in another given all of the parameters that can affect indoor air quality. The results presented in this paper illustrate some of the data obtained in this study. To properly complete the comparison between schools it is necessary to assign weighting factors to these data and to develop an algorithm that compiles the weighted data into one or more summaries. The authors hope to develop this algorithm using the TESIAS data, which will continue to be mined over the next year.

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