HEALTH, ENERGY AND PRODUCTIVITY IN SCHOOLS: OVERVIEW OF THE RESEARCH PROGRAM

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ABSTRACT
A research program has been initiated to focus on obtaining quantitative data in existing elementary schools through a longitudinal study with controls, interventions, and cross-sectional components. The overall objective of this program is to quantify the effects of simultaneous control of indoor exposures (i.e., thermal, indoor air quality or IAQ, lighting, and acoustics) on specific measures of human response, student and teacher performance, and productivity. The pilot study is being conducted in six elementary schools in Montgomery County Maryland. Two matched triplets of schools have been selected, each with three 3rd grade and three 4th grade classrooms. Exposure, questionnaire, and system performance data are being acquired periodically before and after interventions. The sets of data being acquired are unique as they provide information on daily profiles of simultaneous exposure to six indoor environmental stressors.

INDEX TERMS
Interventional study, Indoor exposures, Human responses, Student performance, Economic effects

INTRODUCTION
While deficient indoor environments have been a long-standing problem, a new "driver" has evolved with the increasing awareness of the direct relationship between indoor environmental (IEQ) control and health. Building managers and other fiscal decision-makers still tend to minimize the value of environmental control. This may be in part due to the absence of scientific, quantifiable data to support decisions addressing the health impacts. Nowhere is this situation more evident or significant than in the school environment, where decisions can result in life-long impacts on student health, learning, and performance.

To address these issues, a research program entitled Health, Energy and Productivity in Schools (HEPS), has been initiated. HEPS focuses on obtaining data in existing elementary schools through a longitudinal study with controls, interventions, and cross-sectional components. The *overall objective* of this program is to quantify the effects of simultaneous control of indoor exposures (i.e., thermal, indoor air quality or IAQ, lighting, and acoustics) on specific measures of human response, student and teacher performance, and productivity. In this study, productivity is defined the value of the measured incremental improvement in performance compared to the cost of achieving the improvement, including energy efficiency and cost effectiveness. The *specific objective* of this pilot study, which is now underway, is to develop and validate a protocol that can be used in a comprehensive study of schools nationwide. The two aims of these studies are to: 1) provide quantitative results to serve the needs of planners

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and policy makers, and 2) become the basis for additional training of practitioners who design, construct, and operate school facilities.

Literature reviews continue to reveal that previous field studies, while interesting, have been uncontrolled or anecdotal. Past field studies have focused on single environmental exposures such as daylighting, IAQ, thermal or acoustics. Results from these studies have also confounded measures of human response, occupant performance and productivity. The intent of this study is to overcome these limitations by developing and validating a protocol through a four year pilot study in one selected school district. The pilot study has been designed to ensure that sufficient data are obtained to allow assessment of the effects of various interventions and to obtain and analyze those data using statistical methods that are acceptable to the scientific community.

METHODS

In April 2000, Montgomery County Public Schools (MCPS) in Maryland agreed to participate in this pilot study. Third and fourth grades were chosen for this study for three key reasons. First, the third grade was the earliest for which standardized records were maintained by MCPS. Second, students in these grade levels have rapid rates of learning. Third, the immune and respiratory systems of students at these grade levels are not yet fully mature.

Three commitments were requested and received from MCPS: 1) that the school district be an active participant in the study; 2) that the study team be given access to the school facilities and appropriate records during the study; and 3) that the school district fund the interventions through their existing budgets for operations and capital improvement plans.

The protocol for the pilot study has evolved in response to comments received from the research team, the sponsors, and the MCPS. The foundation for the protocol was derived from research on the evolution of "Building Diagnostics Procedures" (Woods, Boschi and Sensharma, 1995), from the ASHRAE Research Project 700RP (Woods, Arora and Sensharma, 1996), and from subsequent research (Sensharma and Woods, 1998) (Woods, Petrisek and Granger, 2000). This protocol followed the six-step procedure defined in the ASHRAE 700RP Protocol, but was specifically adapted to focus on the effects of environmental control in elementary schools. The six steps are:

Step 1: Define study objectives and identify the classrooms for evaluation.
Step 2: Define evaluation criteria.
Step 3: Obtain and analyze pre-intervention data.
Step 4: Identify and implement interventions.
Step 5: Obtain and analyze post-intervention data.
Step 6: Interpret data and make recommendations.

RESULTS

This paper reports on the results, to date, of this longitudinal study which is not scheduled for completion until the end of 2003. At this time, Step 1 is completed, Step 2 is completed except for economic criteria, and two cycles of pre-intervention (baseline) data have been acquired in Step 3. In Step 4, the schools that will receive interventions have been identified and the designs for the interventions have been initiated. Step 4 is scheduled for completion by Fall 2002. Step 5 will be completed in the summer of 2003, and Step 6 is scheduled for completion in December 2003.

Hypotheses

In Step 1, two sets of hypotheses were agreed upon for this study:

1) Indoor environmental quality (IEQ) control has quantitative effects on health and performance of elementary school children and their teachers, with consequential economic impacts.

1a) Independent factors of lighting, acoustic control, indoor air quality (IAQ), and thermal control have quantitative effects on health and performance of elementary school children and their teachers, with consequential economic impacts.

2) The rate of return on incremental costs for improved IEQ is sufficient to justify a redirection of spending priorities for education.

2a) The rate of return on incremental costs for improved IAQ, alone, is sufficient to justify a redirection of spending priorities for education.

To test the first set of hypotheses, measures of educational outcomes, health status, and student performance are being obtained in Steps 3 and 5 through records maintained by MCPS and from responses to a questionnaire that has been developed for this study (Freitag, Woods, Sensharma et al, 2002). Teachers of third and fourth grade students also provide their perceptions of environmental "acceptability" in response to the questionnaire. At the same time, "non-intrusive" measures of the indoor environment are being obtained (i.e., thermal, indoor air quality, lighting and acoustic parameters). Measures of environmental system performance (e.g., loads, capacities, and controllability) are also being obtained from the school system facilities division during Steps 3 – 5. To test the second set of hypotheses, agreed-upon methods of benefit/cost analyses will be conducted in Steps 5 and 6 to determine the "value" of the changes in the health and performance of students and teachers with respect to the costs of intervention and subsequent changes in operating and maintenance costs.

Experimental Design

A modified Latin square design has been selected to test for significant differences in indoor environmental quality, human response, performance and productivity for each site between the pre-intervention and the post-intervention academic years. Each classroom within each school site serves as its own control with regard to indoor environmental factors between the pre-intervention and post-intervention. Cross-sectional comparisons, possible at any point in the study, may show significant differences between school sites, or among classrooms within each site.

Longitudinal data on student responses and performances are expected to be confounded by the reassignment of students between grades and into different classrooms. This is a possible limitation as well as a possible strength of this design. Because not all students from a particular 3rd grade classroom will move into the same 4th grade classroom, the assignments are essentially random within the design of the study. Consequently, the design is a "mixed model" with fixed effects being those of site and classroom characteristics, and random factors of teacher and student assignment.

School and Classroom Selections

From the population of all 124 elementary schools in the MPCS, three matched schools were selected from each of the two demographic locations chosen for the pilot study, urban and suburban areas in the Fall of 2000. Within each of these schools, three 3rd grade and three 4th grade classrooms have also been selected. The criteria for selection of these schools and classrooms were:

Three or more 3rd and 4th grade classrooms per school. As the interventions will most likely pertain to several classrooms, all classrooms on a corridor, or throughout the entire facility, schools with at least three third and fourth grade classrooms were required for statistical reliability. A power calculation indicated that the resultant 36 classrooms, with an assumed occupancy of 20 students each (i.e., 720 students), would provide an adequate sample size to detect improvements in reading and math based on Criterion Reference Test (CRT) scores with a power of 80% and less than a 5% chance of a Type I (i.e., false positive) error.

Classification as P3 or higher. Visual inspection, review of previous health reports, and building condition assessment were part of the Phase 1 diagnostics implemented to classify and select the participant school sites (Woods, Arora, Sensharma, et al, 1996). Schools with elevated frequencies of reported symptoms (P2) or clinical signs of illness (P1) were excluded from the Pilot Study, as it is highly likely and desirable that mitigation would occur immediately after discovery (i.e., during the study period).

Demographic classification. The remaining candidate schools were classified into two demographic locations: urban and suburban. Based on information obtained from MCPS, the schools are grouped by "clusters." Clusters are identified as those schools within a certain high school's attendance area. The urban location has five clusters and the suburban location has 14 clusters. A Total of 35 schools remained in the pool based on these criteria.

Match schools on exogenous factors. Schools within demographic locations were matched as closely as possible with regard to eight sets of exogenous factors that were identified with the help of MCPS. These factors, which cannot be controlled in this study, are: percent student mobility (i.e., transfer rate); percent "white" population in the school; percent of students receiving Free and Reduced Meals; percent of students enrolled in English for Students of other Languages, percent of 3rd grade students passing acceptable CRT math scores, percent of 3rd grade students passing acceptable CRT reading scores, percent of 4th grade students passing acceptable CRT math scores, and percent of 4th grade students passing acceptable CRT reading scores. A total of 10 schools remained in the pool based on the matches found by this criterion.

Select six schools. Based on a Phase 1 Diagnostics of these 10 schools, which included interviews with the Principals, two matched triplets were selected. And within each of the schools, three 3rd grade and three 4th grade classrooms were selected. Within each matched triplet, one school will serve as the "control school" and the others will be assigned to an appropriate intervention level.

Evaluation criteria

In Step 2, The evaluation criteria to be used in the pilot study have been derived from two rational models (Sensharma and Woods, 1998). The earlier model described relationships between human response, indoor exposure, system performance, sources or loads, and energy and economic performance. The subsequent model extended this concept by demonstrating that measures of human response, occupant performance and productivity parameters were related but not synonymous. *The values for the relevant parameters in this Pilot Study have been defined as a set that are to be controlled simultaneously to meet the expected performance of the students, teachers and facilities*. The values for the human response and exposure criteria are based on information obtained from the literature and experience. The values for the other criteria are based on information for this study provided by MCPS. Compliance with

these criteria will be the basis for the design of the two levels of interventions in Step 4. Further details on the values of these criteria and the specific interventions will be reported elsewhere.

Pre-intervention Data

Data acquisition for evaluation of the parameters defined by the evaluation criteria was initiated as Step 3 in October 2001 and will be obtained periodically throughout the academic year. To meet the objectives of the study and to minimize intrusion on teachers and students, the instrumentation being used to collect data in the classrooms on the scheduled sampling days is limited to: 1) questionnaires (see Freitag, et al, 2002) that are self-administered by the teachers in the classrooms; and 2) six brief-case sized packages of sensors, monitors and samplers of exposure parameters that are located in the classrooms before the classes begin and retrieved after the classes end. Other instrumentation will also be used to collect data in the classrooms during unoccupied periods and outside of the classrooms. A detailed explanation of the instrumentation package is beyond the scope of this paper and will be reported elsewhere. The results from the questionnaires and from the data acquired from MCPS will not be analyzed until the completion of the post-intervention acquisition period.

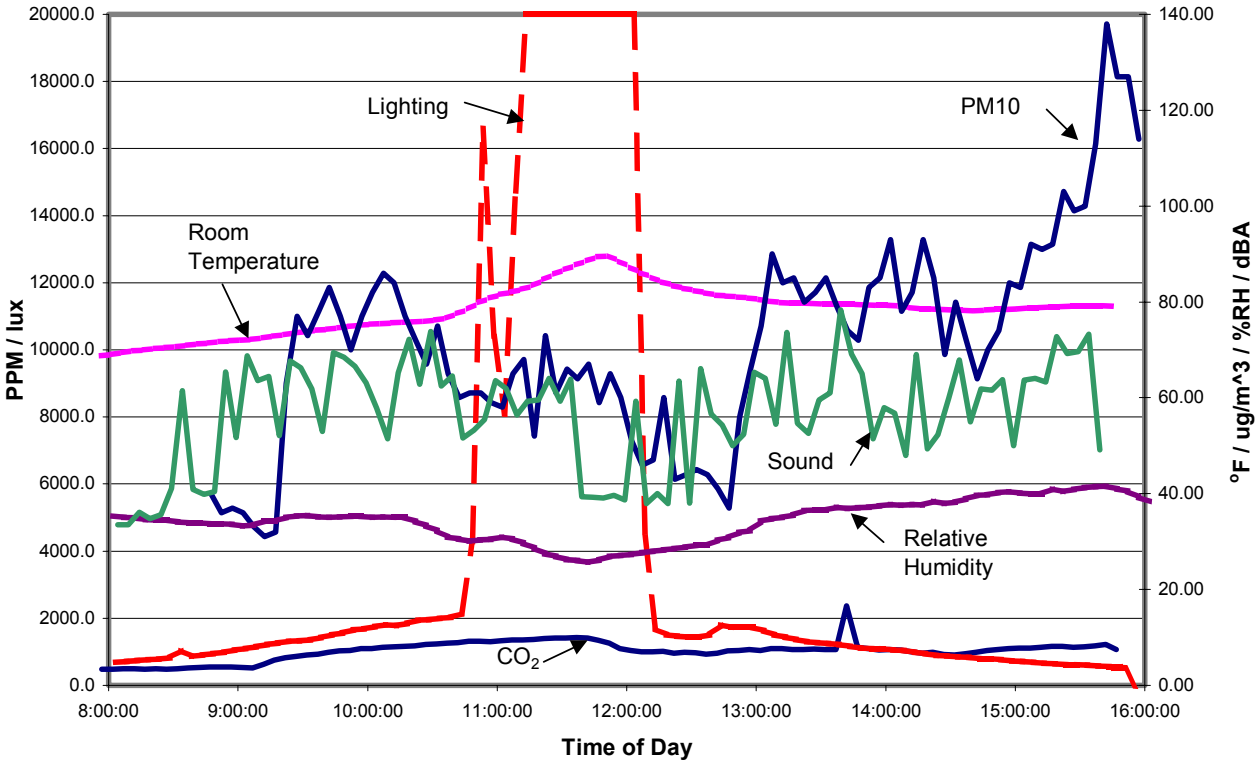

Figure 1. Typical daily profile of exposure data obtained in one of the classrooms during Fall 2001.

DISCUSSION

An example of a set of exposure data obtained in a classroom during the first cycle of data collection is shown in Fig. 1. These data indicate a daily pattern of exposures to six environmental parameters. They also indicate an apparent relationship between the lighting levels, room temperature and relative humidity, and between the sound levels and PM10 and CO_2 concentrations. The location of the instrumentation package was in front of the teacher's

desk that was near a south-facing window with the blinds pulled up. The window was shaded in the afternoon by an adjacent east-facing wall. Although, it is premature to analyze these data in detail, Fig. 1 provides a good indication that sensitive exposure data are being obtained in the occupied classrooms. A review of the literature and discussions among the participating researchers and sponsors indicates that these data may be unique as they provide quantitative information on the combined exposures to these six environmental parameters.

CONCLUSION AND IMPLICATIONS

The progress made in this study leads from conventional methodologies to methodologies that incorporate experimental designs which are more prevalent in the health and social science fields. The results obtained so far in this study also lead to the conclusion that daily profiles of exposure parameters provide quantitative data on total exposure during occupied conditions and that these conditions are significantly different than typically assumed during the design of the facilities. Finally, the progress in this study provides encouragement that complex studies on the effects of the indoor environment can be successful but require significant commitment from the community, from industry and from government agencies.

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