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An assessment of indoor environmental quality in schools and its association with health and performance

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ABSTRACT

In order to examine the associations between different indoor environmental quality (IEQ) indicators and students' performance, absenteeism and health data were collected, and sampling and monitoring were conducted in a 70 school district in the Southwestern United States during two academic years. These included measurements of temperature (T), relative humidity (RH), carbon dioxide (CO_2), and settled dust. A standardized cleaning protocol was employed for surface sampling and cleaning effectiveness evaluation utilizing adenosine triphosphate (ATP) monitoring systems to detect biological contamination, and contact agar (RODAC) plates to detect culturable bacteria. In addition, student data related to socioeconomic background, absenteeism, performance, and number of visits to school nurse was retrieved anonymously from the school district. Significant associations were observed between percentages of students scoring satisfactory in mathematics and reading tests and both indoor T ($r = -.353$ and $r = -.311$ respectively) and ventilation rate ($r = .417$ and $r = .479$ respectively), which was estimated based on CO_2 levels. In addition, ventilation rate was associated with mean number of visits to school nurse due to respiratory symptoms, and culturable bacteria with mean number of visits due to gastrointestinal symptoms; but there were no significant correlations between absenteeism and IEQ parameters in these school-level analyses. In conclusion, classroom ventilation rate, temperature, and hygiene of high contact surfaces appear to be important IEQ parameters, potentially related to student health and/or performance.

1. Introduction

It is recognized that poor indoor environmental quality (IEQ) in schools may result in illness leading to student absenteeism, as well as adverse health symptoms, and decreased academic performance [1–4]. Various biological and chemical pollutants and their interplays may contribute to IEQ [5,6]. In addition, physical factors may modify the body response to indoor pollutants by interacting with it or have a direct effect on the occupants [7].

An earlier study of one hundred elementary schools from two school districts in the Southwest United States found that 87% of classrooms studied (one classroom per school) had ventilation rates below 7.1 l/s per person [8]. The 7.1 l/s per person value was the minimum prescribed rate in the 2004 version of ASHRAE Standard 62, and is comparable to the 2013 version of the ASHRAE Standard. In addition, there was a linear association between classroom ventilation rates and students' academic achievement within the range of 0.9–7.1 l/s per person. Further analyses indicated that classroom ventilation rates correlated significantly with mean indoor and outdoor temperatures (T), indoor $PM_{2.5}$ readings, and outdoor relative humidity (RH) [9]. Other studies conducted in cold climates have also associated low ventilation along with high indoor temperature with decreased air quality [10–12]. A Swedish experimental study recommended both sufficient air exchange and air conditioned building for a better classroom indoor air quality and thermal comfort [11].

Lack of maintenance coupled with inadequate cleaning practices can alter the ecosystem of school building and encourage the

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growth and spread of microorganisms that can put students' health at risk. Hussin et al. (2011) found schools with unhygienic conditions are more prone to have high concentrations of both fungi and bacteria due to dusty floors and moldy surfaces like indoor furniture [13]. The study also found occupants to influence indoor bacterial concentration but not fungal concentration. In another study, all room surfaces sampled in a child-care facility were contaminated with bacteria [14]. One way to reduce the spread of disease-causing microbes in schools is to teach personal hygiene to students [15]. However, effective cleaning practices appear to be equally important.

This study broadens the assessment of IEQ in an independent school district located in the Southwestern United States, including an assessment of surface cleanliness as well as ventilation rate, thermal conditions, and an analysis of settled dust. An aim was to study the relationships between different measures of IEQ, and their associations with performance, absenteeism, and health of students.

2. Material and methods

2.1. First school year monitoring and sampling

A district with 70 elementary schools participated in the study. The schools were surveyed and monitored for assessment of IEQ during the academic year of 2008–2009. Background information was collected by walkthroughs utilizing pre-designed checklists, addressing all building structural and operational components, such as building age and design, construction, finishing, and furnishing materials, impact history (e.g. damage, repairs, renovations, retrofits), maintenance schedules, cleaning methods and frequencies, etc.

Field measurements consisted of temperature (T), relative humidity (RH), carbon dioxide (CO_2), and settled dust. Fourteen TSI QTrak Monitors were rotated on a weekly basis to seven new schools between January 26 and April 18, 2009 for continuous logging of two fifth grade classrooms from each school for T, RH, and CO_2 (5-min resolution).

Settled dust boxes were deployed in two classrooms in each school (two per classroom, a total of 280 boxes). The boxes were placed adjacent to each other on an unsheltered shelf area in each classroom at a height of approximately two meters above the floor for a minimum period of three months (between January 20 and May 11, 2009), after which the boxes were recovered to assess the quantitative gravimetric amount of dust and a “percent surface coverage” metric. Gravimetric analysis was conducted by vacuuming dust onto a 37 mm filter cassette, and then weighing on a Mettler-Toledo XS104 analytical balance. The reported amount of dust was quantified by milligrams per square meter per month. The percent surface coverage was determined by use of a BM-DustDetector technology, where an average of three readings with the Dust Detector was calculated. A comparison of the gravimetric analyses vs. the Dust detector values is described in an earlier study [16].

2.2. Second school year monitoring and sampling

Twenty seven schools from the 70-school district were randomly selected for further monitoring, as well as assessment of cleaning effectiveness by surface sampling conducted during the academic year of 2009–2010. Surface sampling included collection of pre- and post-cleaning data from critical contact transmission surfaces in classrooms, restrooms, and cafeterias, using three different monitoring systems to detect and quantify adenosine triphosphate (ATP), which is a well-recognized marker for biological contamination. In all ATP surface sampling, swabbing of surfaces was taken using a predesigned 25 cm^2 template. In addition, levels of total culturable bacteria were quantified using contact agar (RODAC) plates. One week at a time was allotted for sampling of the selected surfaces in each school over a 3-day period (one day for each ATP system) within the week. Thus, 27 schools were utilized over a 30-week period (between 11 October 2009 and 28 May 2010).

For each school, two fifth grade classrooms were selected for ATP and RODAC sampling of student desks. Ten total desk surfaces were selected for sampling each day. In the cafeteria areas, five cafeteria tables were selected and divided into two halves for a total of ten cafeteria sampling surfaces each day. For bathroom areas, two restrooms in each school were selected (one girl's and one boy's). In the bathrooms, a total of ten sink areas and ten stall doors were selected for sampling each day. The selected surfaces were sampled for ATP and RODAC pre-cleaning, they were then cleaned using the prescribed cleaning and disinfection protocol, and then sampled again for ATP and RODAC post-cleaning values. Whereas the results from different ATP systems were significantly correlated both before and after the cleaning, the results using RODAC were correlated with only pre-cleaning ATP. More detailed analysis of ATP and RODAC data for assessment of cleaning effectiveness have been reported elsewhere [17]. In this study, the results from using one ATP system NovaLUM (Charm Sciences, Inc., Lawrence, Kans.) and RODAC (Item #823002; Carolina Biological, Burlington, N.C.) were selected for further analyses.

2.3. Cleaning protocol

For the surface sampling and evaluation of cleaning effectiveness, a standardized approach to the cleaning and disinfection of critical surfaces was developed based on the cleaning products available in the school district at the time. A one-step cleaner/disinfectant with bactericidal, fungicidal, and virucidal capabilities was used in conjunction with microfiber cleaning cloths. All cleaning was done by a trained research team to ensure that the protocol was followed precisely in each school building, thus eliminating school-to-school variability among cleaning personnel.

Parallel to surface sampling, further monitoring included measurements for T, RH, and CO_2, and settled dust similar to what had been recorded during the 2008–2009 school year. In addition to the school maintenance and operation checklists and individual classroom checklists, housekeeping services campus evaluation reports from all schools were collected and assessed, including a summary sheet for overall cleaning evaluation based on visual observation.

2.4. Student data

Anonymous student individual, and classroom level composite data for 2008–2009 and 2009–2010 were obtained from the District to profile each of two 5th grade classrooms in every school (140 classrooms monitored in 2008–2009; in 2009–2010 focus was directed toward the 27 schools where surface samples were being collected) related to students' socioeconomic background, absenteeism, and academic performance. Background information of the 5th graders by school included percent of students by different ethnic groups (Native American, Asian, African American, Hispanic and Caucasian), gender, gifted or talented, eligible for free or reduced lunch, and limited English proficiency. Absenteeism data included total days of absence, and absence days due to illness by fifth grade students in the classrooms measured. These data were normalized by the number of students attending these classrooms, corresponding to average number of days absent per student.