4209

INDOOR AIR QUALITY IN 12 SCHOOLS: A CASE STUDY

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ABSTRACT

An investigation of indoor air quality in 12 schools in Alberta was conducted to evaluate the relationship between type of ventilation system, occupant health and comfort, and levels of specific indoor pollutants. Three categories of schools were investigated: (1) schools constructed prior to 1960 with no modification to mechanical systems, (2) schools constructed prior to 1960 which have been upgraded to meet current building codes, and (3) schools constructed since 1960.

A questionnaire survey was administered to teachers, administrators, and custodial staff. Common health and comfort complaints reported by occupants of all school types included: headache, fatigue, eye irritation, sore throat, too little air movement, stuffiness, and poor temperature control. The highest prevalence of health and comfort complaints were reported by occupants of schools constructed since 1960.

Based on the results of the questionnaire, three schools (one from each category) were selected for further evaluation of air quality parameters by physical measurement. Carbon monoxide, respirable particles, temperature, relative humidity, and airborne microbial levels were similar in all three schools and were far below established air quality guidelines. However, carbon dioxide (CO_2) concentrations varied substantially within and between schools, exceeding, at times, 1000 ppm in classrooms of each school. The highest CO_2 concentrations (2000 to 2800 ppm) were measured in portable classrooms. The elevated CO_2 concentrations indicate that the ventilation systems, as operated, were ineffective in meeting the outside air requirements. Total outside air requirements in classrooms are greater than for other areas within the schools because of the high density of students.

Recommendations to improve indoor environmental conditions in the three schools included an overhaul of outside air dampers, relocation of supply air registers, and continuous operation of ventilation systems during occupancy of portable classrooms.

INTRODUCTION

An investigation of indoor air quality in 12 schools in Alberta was conducted to evaluate the relationship between age of construction, type of heating and ventilation system, occupant health and comfort, and levels of specific indoor pollutants. The study was conducted during March and April 1988.

Twelve school buildings, representing specific age groups and types of mechanical systems, were chosen for the study. The chosen schools were typical of many schools in the province of Alberta. The 12 schools were categorized into three types:

1. Old: Construction prior to 1960, with no modifications to the original heating and ventilating systems.
2. Renovated: Construction prior to 1960, with heating and ventilation system upgrades to current building codes.
3. New: Constructed since the early 1970s, representing a modern, "tighter" approach to building technology.

METHODS

The study utilized a phased approach for building performance evaluation, which has previously been used in field evaluations of offices and other public buildings in North America and Great Britain (Sterling et al. 1987). The approach provided a time- and cost-effective means of evaluating the schools.

Phase One

Phase One consisted of a review of each of the 12 schools' architectural and mechanical systems design, operation, and maintenance practices.

The major architectural components of the buildings were reviewed and identified. The age of construction, the type of interior finish, floor covering, type of windows, etc., were examined for sources of indoor air contaminants.

The heating and ventilation systems were reviewed in detail. The method of delivering supply air to, and removing return and exhaust air from, a typical classroom was identified. The location of outdoor air intakes was compared to the location of the discharge from return and exhaust fans, to evaluate the potential for re-entrainment of fumes.

Phase Two

Phase Two, also carried out on all 12 schools, consisted of the administration of a "Work Environment Survey" questionnaire to building occupants (teachers, administrators, and custodial personnel, but not students) to quantify the type and extent of the environmental comfort problems and health-related symptoms experienced by occupants.

The Work Environment Survey is a self-administered, machine-readable questionnaire that has been used previously to survey occupant perceptions in offices and other public buildings.

The questionnaire is designed to obtain three categories of information:

1. Demographic and occupational characteristics of the building occupants, for example, age, sex, educational background, and job type.
2. Occupant perceptions of satisfaction and dissatisfaction with indoor environmental conditions, including air movement, humidity, temperature, lighting, and noise conditions.
3. Occupant perceptions about health-related symptoms. The health symptoms are divided into two general groups—one that has been frequently related to poor air quality and the "sick building syndrome," and one that is not directly related to air quality, but more to stress factors in the workplace.

The Work Environment Survey is designed to determine the frequency of response to each health and comfort question using a four-point scale of "never," "rarely," "sometimes,"

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or "always." For the purposes of data analysis, the "sometimes" and "always" were combined to provide indication of the most prevalent health and comfort complaints.

Based on the results of Phases One and Two, three schools were selected (one each from the Old, Renovated, and New categories) for continued evaluation in Phase Three.

Phase Three

Phase Three was a detailed indoor air quality evaluation, carried out in the three selected schools. Measurements were taken at sampling sites throughout each school building and at an outdoor site.

The following indoor air quality parameters were measured in each school:

1. Carbon dioxide (CO_2) as an indicator of ventilation adequacy. CO_2 was measured using direct-reading colorimetric detector tubes and a portable digital readout infrared analyzer.
2. Carbon monoxide (CO) as an indicator of combustion byproducts, such as automobile exhaust infiltrating from outside the building or from gas-fired appliances. CO was measured with a portable electrochemical analyzer.
3. Temperature and relative humidity as indicators of occupant thermal comfort conditions in the schools. These parameters were measured using a digital readout indicator equipped with a fast response electronic probe.
4. Respirable suspended particles (RSP) as an indicator of the efficiency of ventilation filtration systems, general cleanliness, and the presence of environmental tobacco smoke. RSP concentrations were determined using a light scattering monitor equipped with a five-micron impactor.
5. Total fungi and bacteria as indicators of airborne microbial loading. Microbial samples were collected with an Anderson sampler using methods recommended by the American Conference of Governmental Industrial Hygienists (ACGIH Committee on Bioaerosols 1986). Bacterial samples were collected on trypticase soy agar and fungal samples were collected on rose bengal agar.

Each school was visited for one day. Two sets of measurements for CO_2, CO, temperature, relative humidity, and RSP were taken at each sampling site in each of the three schools. One set of measurements was taken during the morning and a second set during the afternoon. Total fungi and bacteria were measured at at least one indoor site and one outdoor site at each school.

RESULTS

Phase One

Architectural and mechanical design and mechanical system operation and maintenance were reviewed in all 12 schools during February 1988. Although the schools in each category—"old," "renovated," and "new"—varied in architectural and mechanical design, the three schools later selected for detailed evaluation may still be considered "typical" and therefore representative of their school type.

The "old" school was constructed between 1949 and 1954 and is of wood frame construction with a crawlspace and built-up flat roof. Heating is provided by two steam boilers and is distributed to perimeter radiation and unit ventilators in each classroom. Each classroom has a thermostat. Ventilation is provided by operable windows and unit ventilators. General exhaust fans are located in corridors and cloakrooms. The exhaust fans and unit ventilators were not operating during the indoor air quality evaluation because teachers find them too noisy to run continuously. Consequently, they are only operated in extreme winter conditions. The school does not have a humidification system.

TABLE 1

Responses to Environmental Questions: 12 Alberta Schools

Environmental Conditons	4 Old Schools (n = 126)	3 Renovated Schools (n = 58)	5 New Schools (n = 146)
	% Sometimes or Always		
Air Movement			
Too Little	61.9	63.8	75.3
Humidity			
Too Dry	84.9	77.6	93.8
Air Quality			
Too Stuffy	65.1	70.7	86.3
Unpleasant Odors	55.6	36.2	58.9
Temperature			
Too Hot	73.8	74.1	85.6
Too Cold	64.3	58.6	74.0
Lighting			
Too Bright	23.8	15.5	28.8
Too Dim	26.2	12.1	26.7
Noise			
Too Noisy	69.0	65.5	66.4

TABLE 2

Responses to Health Questions: 12 Alberta Schools

Symptoms	4 Old Schools (n = 126)	3 Renovated Schools (n = 58)	5 New Schools (n = 146)
	% Sometimes or Always		
Headache	54.0	46.6	71.2
Fatigue	73.8	26.0	78.1
Sleepiness	47.6	43.1	62.3
Eye Irritation	38.9	31.0	53.4
Sore Throat	46.0	39.7	60.9
Nose Irritation	44.4	32.8	56.2
Cold/Flu	53.2	41.4	52.1
Skin Dryness	49.2	46.6	44.5
Backache	38.9	41.4	41.1
Neckache	28.6	32.8	46.6
Tension	40.5	41.4	47.3

The "renovated" school was originally constructed in 1953, with subsequent additions in 1956, 1957, 1960, and 1985. In 1985, the school was completely modernized. The school is a combination wood frame and masonry construction with slab on grade. Heating is provided by two hot water boilers and distributed by wall fin radiation. Ventilation is provided by four air-handling units. Air is distributed to perimeter classrooms through under-slab ductwork that was reused during renovation. Air is distributed through ceiling-based systems to the gym, library, and administrative areas. Each air-handling unit is equipped with a pan humidifier.

The "new" school was constructed in 1980 and is masonry with slab on grade. In addition, six wood-frame portable classrooms are attached to the main school building. Heat is provided to the main school by two hot water boilers that serve perimeter radiation. A thermostat is located in each classroom. Additional heating to interior areas is provided

by reheat coils in the ventilation system. Ventilation is provided to classrooms by a central ventilation unit. The gym and auditorium/lunchrooms have separate ventilation units. Air is delivered to the spaces through ceiling-based systems. Each unit has steam humidification, which was not operating during the air quality tests.

The portable classrooms attached to the new school are heated and ventilated by residential-type furnaces. The furnace fans are set for intermittent operation and would only operate when heating is required (i.e., non-continuous operation). The portable classrooms are not humidified.

Phase Two

Following the architectural and mechanical review of the 12 schools, the "Work Environment Survey" questionnaire was administered to teachers, administrative, and custodial staff in each school. Tables 1 and 2 summarize the results for each "group" of schools.

Table 1 shows the most prevalent complaints about indoor environmental conditions. The table shows the percentage of respondents in each type of school who reported that the particular environmental conditions "sometimes" or "always" occurred at work. The pattern of response was similar for all three types of schools with the most prevalent problems reported as too little air movement, air too dry and too stuffy, and fluctuating temperatures. Lighting was not perceived to be a problem. However, more than 60% of the occupants of all schools reported that it was sometimes or always "too noisy," a complaint consistent with noisy students! Although the pattern of response was similar for all three categories of schools, the most prevalent complaint was generally reported in the new schools, as illustrated in Figure 1. As the six environmental parameters show, occupants of the new schools reported the highest prevalence of complaint.

Table 2 shows the most prevalent health symptoms reported by occupants of each category of school. The pattern of symptoms reported in all three school categories was similar. The most prevalent health complaints included: headache, fatigue, eye irritation, sore throat, nose irritation, colds/flu, and skin dryness. This symptom complex is similar to the types of health complaints typically associated with sick building syndrome (Stolwijk 1984).

Symptoms not generally associated with sick buildings, such as backache, neckache, and tension, were also similar in all three school categories. These symptoms are more stress-related. The prevalence rates found in the schools are generally higher than have been found in office buildings using the same questionnaire survey, suggesting a perceived high level of workplace stress in the teaching profession.

Figure 2 illustrates the comparative prevalent rates in the three types of schools for the most commonly reported symptoms. For the six symptoms shown, occupants of the new schools reported the highest rate of complaint. Occupants of the renovated schools reported the lowest rate of symptoms.

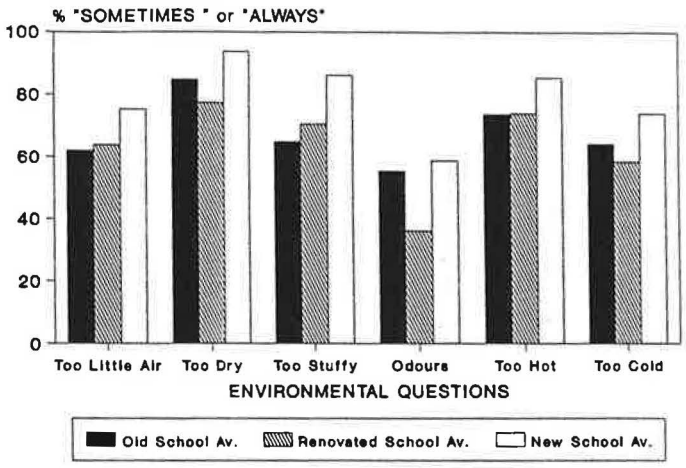

Figure 1 Environmental question responses—school category averages

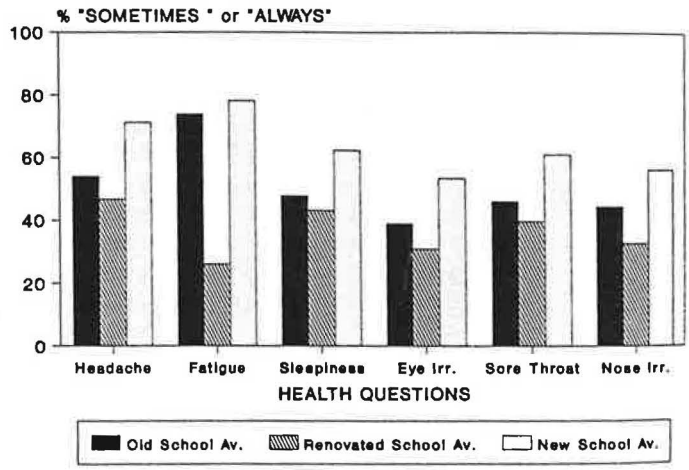

Figure 2 Health question responses—school category averages

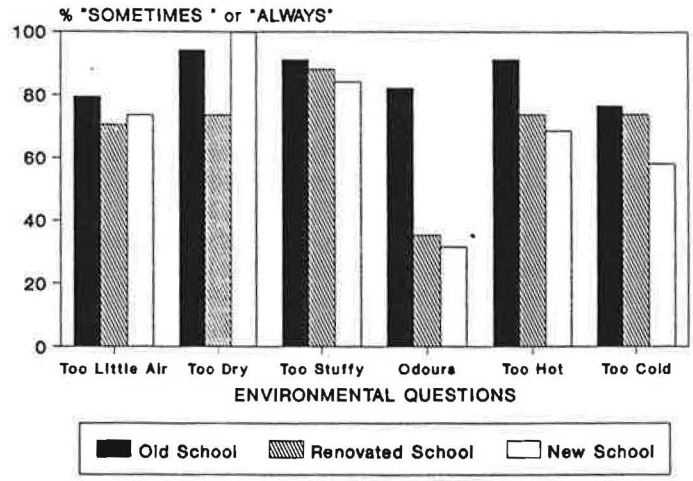

Figure 3 Environmental question responses—schools selected for Phase Three

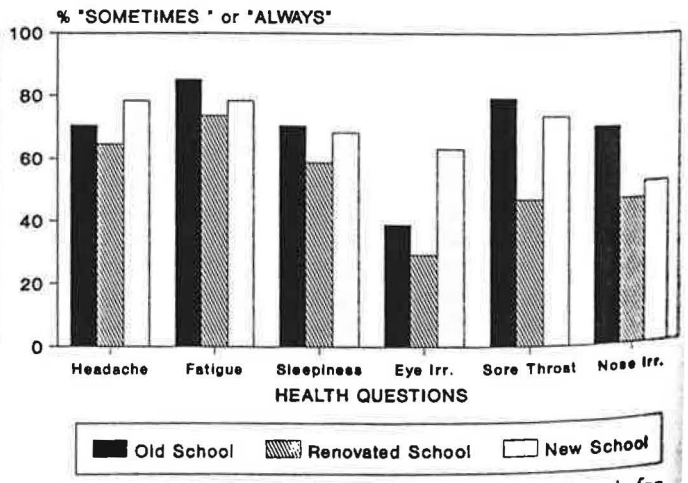

Figure 4 Health question responses—schools selected for Phase Three

TABLE 3

Mean and Ranges of Measured Indoor Air Quality Parameters: Three Alberta Schools, March 1988

	Old School	Renovated School	New School	Portable Classrooms
Carbon Dioxide (ppm)	750 (500–1100)	750 (550–1400)	650 (500–900)	1950 (1000–2800)
Outdoor	350	400	350	350
Carbon Monoxide (ppm)	1.3 (1.0–1.8)	1.1 (0.7–1.5)	0.9 (0.7–1.1)	0.9 (0.8–1.0)
Outdoor	2.1	11.5	1.1	1.1
Temperature (°C)	22.8 (21.6–24.8)	22.6 (21.3–24.8)	22.9 (22.5–23.8)	23.6 (23.2–24.1)
Outdoor	8.6	3.5	6.3	6.3
Rel. Humidity (%)	14.2 (11.3–17.8)	18.6 (13.8–27.2)	17.1 (15.3–21.3)	26.6 (24.1–31.2)
Outdoor	23.6	39.9	38.5	38.5
Resp. Particles ($\mu g/m^3$)	16 (11–22)	13 (10–20)	14 (10–17)	17 (15–20)
Outdoor	23	15	18	18
Total Bacteria (cfu/m^3)	386 (230–489)	137 (129–145)	388 —	—
Outdoor	486	202	106	—
Total Fungi (cfu/m^3)	175 (89–269)	98 (55–141)	56 —	—
Outdoor	150	78	51	—

In addition to analysis of questionnaire responses for each category of schools, individual school responses were analyzed to select one school from each group for further evaluation. The "worst case" school (i.e., that with the highest rate of health and comfort complaints) from each category was chosen. Figures 3 and 4 show the questionnaire responses for the most prevalent complaints in the "worst case" schools. A lack of air movement, dryness, and stuffiness were the prevalent comfort problems in all three schools, with the highest reported problems in the old school. Occupants of both the old and new schools reported similar rates of health complaints. Prevalence rates for the health symptoms were slightly lower in the renovated schools.

Phase Three

The findings from the indoor air quality evaluations undertaken in the three selected schools are shown in Table 3. For each air quality parameter, the mean level, range of values (in parentheses), and outdoor levels are given. Data are also shown for the portable classrooms attached to the new school.

Carbon dioxide concentrations were lowest in the new school, ranging from 500 to 900 parts per million (ppm). CO_2 levels in the old and renovated schools were highest in occupied classrooms, exceeding the 1000 ppm level used to indicate "adequate ventilation" in ASHRAE Standard 62-1989 (ASHRAE 1989). By far the highest CO_2 concentrations found in the three schools were in the portable classrooms. All measured values exceeded 1000 ppm, with a maximum of 2800 ppm. The elevated CO_2 concentrations in occupied classrooms in all schools illustrated the particular demands placed on mechanical systems by a high density of students. Only the mechanical systems in the new school were able to cope with such demands. In the old and renovated schools and in the portable classrooms, the outside air delivery was inadequate to meet occupant requirements.

Carbon monoxide concentrations were low in all schools. Indoor levels were generally lower than outdoors, indicating that neither the infiltration of fumes from outdoors nor combustion byproducts from gas-fired equipment was a problem.

Mean temperature levels were similar in all three schools (between 22°C and 23°C), despite outdoor variations. There was a wider variation in indoor temperatures within the old and renovated schools, compared to the new school. To assess the impact of the measured temperatures upon occupant comfort, the results can be compared to the comfort range defined in ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy," which defines a winter comfort range of 19°C to 24.5°C (ASHRAE 1981). Almost all temperature measurements in the three schools were within this comfort range. There were only two exceptions—one classroom in each of the old and renovated schools.

The relative humidity levels found in the three schools can also be compared to the 20% to 80% range of comfort defined by ASHRAE Standard 55-1981. Mean relative humidity levels in all three schools were below 20%. Additional research conducted for Health & Welfare Canada has suggested that 40% to 60% relative humidity would be optimal for human comfort (Sterling et al. 1985). The low humidity levels in the schools correspond with the prevalence of occupant-reported problems of "air too dry" in Phase Two.

Respirable particle concentrations were similar in all three schools, ranging from 10 to 22 micrograms per cubic meter ($\mu g/m^3$). Indoor levels were generally lower than outdoors. The low RSP concentrations indicate effective filtration and good janitorial practices in the schools.

Airborne microbial concentrations were highest at the old school, with a total bacterial concentration of 386 colony-

forming units per cubic meter (cfu/m³), and a total fungal level of 175 cfu/m³. However, outdoor concentrations were also highest at the old school. Air quality standards have not been established for airborne microbes. However, research by Morey (1984) has suggested that microbial concentrations in excess of 1000 cfu/m³ indicate possible microbial contamination and warrants further investigation. All microbial concentrations in the three schools were well below the 1000 cfu/m³ level of "concern."

DISCUSSION

The findings from the study of the 12 schools clearly shows that occupants of schools experience similar indoor environmental problems to office workers. The survey showed a complex array of health and comfort complaints that have been commonly reported in other office and public buildings. A higher prevalence of health and comfort problems was reported by occupants of new schools (built using modern, tight construction technology) when compared to old and renovated schools. However, the subsequent measurements showed few differences between the indoor air quality in the three types of schools. In each of the old, renovated, and new schools, measured parameters were within established guidelines, with the exception of CO_2. Using a CO_2 concentration of 1000 ppm as an indicator of ventilation adequacy, inadequate delivery of outside air was found in classrooms in the old and renovated schools and also in the portable classrooms attached to the new school. The high CO_2 levels in classrooms suggests that the human-generated CO_2 in occupied classrooms is not being controlled by the ventilation systems. A consequence of ventilation-related problems in the schools is the high rate of complaints such as a lack of air movement and stuffiness, which may also be linked to health symptoms such as headache, fatigue, and sleepiness.

The Phase One evaluation (review of plans and inspection) showed possible deficiencies in the heating and ventilation systems in each school. The impact of these deficiencies on occupant health and comfort was determined in the subsequent questionnaire surveys.

Based on the findings of the overall evaluation, recommendations were made to improve the function of the mechanical systems, which in turn would have a positive effect on the indoor environment. Recommendations included overhaul of the unit ventilators in the old school and consideration of system redesign, relocation of supply air registers in the renovated school to improve air distribution, and ductwork modification and acoustical treatments in the portable classrooms to allow continuous operation of the furnace circulation fans.

ACKNOWLEDGMENT

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DISCUSSION

Carl N. Lawson, LRW Engineers, Tampa, FL: How did you handle the CO-CO_2 in these schools?

D.M. Cousins, Keen Engineering Co. Ltd., Vancouver, BC, Canada: CO and CO_2 (and respirable particles, temperature, and relative humidity) were measured once in the morning and once in the afternoon at locations throughout the schools (classrooms, labs, staff rooms, library, offices) and at one outdoor site.

Lawson: With your outside air intakes located in the side of the penthouse, weren't you concerned about contaminants from the rainwater build-up being brought into the HVAC system? Also, why not put outside air intakes on-roof with goosenecks?

Cousins: The velocity of the outdoor air is kept below 500 ft/min so that there is virtually no entrainment of moisture or dust. Architects do not generally like goosenecks on the roof and we try to keep them to a minimum.

James E. Woods, Honeywell Indoor Air Quality, Golden Valley, MN: On what basis can you conclude that the air quality was "acceptable" given the high frequency rates of complaints you reported?

Cousins: The conclusion of "acceptability" was based upon comparison of the physical air quality measurements with available air quality standards. Certainly, the high frequency of complaints would suggest that the air quality may not have always been "acceptable" over the period of recall for the questionnaire (six months).

Ed Light, Biospherics Inc., Beltsville, MD: What were the times and location of the samplings?

Cousins: As mentioned, CO, CO_2, RSP, temperature, and relative humidity levels were measured at locations throughout the schools, twice during the day of sampling—once in the morning and again in the afternoon. Airborne microbial samples were collected at two or three locations in each school and also at an outdoor site.