USE OF ENERGY RECOVERY VENTILATORS TO PROVIDE VENTILATION IN SCHOOLS AND THE IMPACT ON INDOOR AIR CONTAMINANTS

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ABSTRACT

This study examines the use of energy recovery ventilators (ERV) in two schools located in a Southwestern arid climate as an energy-efficient means of providing acceptable ventilation to the classrooms and the corresponding effect on indoor air quality (IAQ) contaminant indicators. The effect of cleaning the existing systems on thermal comfort conditions were also examined. IAQ measurements were made in selected classrooms with respect to carbon dioxide, viable and non-viable bioaerosols, volatile organic compounds, and respirable particles. Measurements were taken with and without the use of the ERV in the classrooms and at selected control classrooms and outdoor sites for reference purposes. Pre ERV results indicated generally poor ventilation and indoor air conditions existed in the classrooms. Improvements in air quality as a function of the ERV use are detailed in this paper for each of the IAQ indicators measured.

INTRODUCTION

The elevated levels of indoor pollutants can be traced not only to significant pollutant sources in schools, but also to inadequate supply and control of outdoor ventilation air. Insufficient outdoor air ventilation to remove indoor pollutants typically results from (a) poor design of ventilation systems -- if a system exists at all, (b) lack of proper maintenance of these systems, and (c) incorrect operation of the ventilation equipment. In addition, efforts to control energy costs by retrofits that reduce the amount of untempered outdoor air that enters a building may impair ventilation rates. To address some of these issues, the University of Tulsa's Center for Environmental Research and Technology (CERT) and the U.S. EPA Radiation and Indoor Environments National Laboratory carried out a project to conduct field measurements of indoor air quality parameters and ventilation rates in selected schools before and after improvements have been made to the ventilation systems. Specific objectives of this study are to, 1) contribute to a growing data base on pollutant levels and ventilation conditions in schools, and, 2) monitor the change in pollutant levels caused by ventilation improvements made to school buildings/rooms.

PROJECT DESIGN

<u>Selection of Schools and Classrooms</u>

Two classrooms in each of two elementary schools in Las Vegas, Nevada were selected for the study. Weather conditions during the summer and fall monitoring periods were hot and dry, with daytime temperatures often exceeding 100° F, and relative humidities less than 20%. One classroom from each school underwent improvements to the existing HVAC system and had an energy recovery ventilator (ERV) installed, and is referred to as the "study room". No modifications were performed in the other classroom at each school -- these classrooms are referred to as the "control rooms". Schools and classrooms selected into the study were required to meet the following criteria (none were selected on the basis of pre-existing IAQ problems):

- operate on a 12-month, year-round school schedule since testing would be conducted under cooling season (summer) conditions,
- at each school, classrooms were to be of approximately the same size and physical configuration, and preferably be adjacent to each other,
- for each pair of "control" and "study" rooms, classes had to be in the same grade level and have approximately the same number of students and teachers,
- because of the staggered schedules in these year-round schools, classes for the paired "study" and "control" rooms had to be in session during the study period.

School "A" was constructed in 1954 with block walls, slab-on-grade floors, and a flat roof. The two classrooms are in a separate wing with 10 other classrooms. The wing consists of a central utility chase with six classrooms backing up to each side. The study and control rooms are side-by-side in the center of six classrooms. The doors of each room open to the outside under a breezeway roof. Windows are not operable, apparently in an effort to conserve energy. Both rooms are carpeted. At the time of monitoring, third grade classes of approximately 25 to 30 students were held in each room. Ceiling-mounted unit ventilators provide heating and cooling (operated by a time clock) to each room via hot and cold water piped from a central boiler and chiller. Each unit has a separate thermostat, while the teacher can select three different blower speeds. Outdoor air (OA) was originally supplied to each unit through the chase from roof-mounted vents. However, by the time of the study, these vents had been removed, dampers in the OA ducts had been closed, and no OA was mechanically supplied.

Both classrooms at School "B" are free-standing portable buildings of wood frame construction with flat roofs sited on asphalt pavement with skirting around the perimeters. Each room has carpeting and only one inoperable window. A ducted main HVAC unit (time clock operated) at the end of each classroom provides heating and cooling on command from a thermostat. An auxiliary window air conditioning unit in both rooms can be manually activated by the teacher when the main unit is unable to meet the cooling load. The OA supply vents for all of the HVAC equipment in these rooms had been closed.

<u>Description of Ventilation Improvements</u>

Improvements to the ventilation were made in two ways. After the first week of measurements and tests had been completed, the original ventilation systems in all four classrooms were thoroughly cleaned. This work included cleaning of the coils and cabinets, and ductwork in the classrooms at School B. Biocides were not used during the cleaning. At the same time, the air filters in all of the equipment were upgraded to pleated filters with a 40% dust spot efficiency.

A second improvement in the two study rooms involved the installation of an "energy wheel" energy recovery ventilator (ERV). The units were designed to provide balanced ventilation of 500 cfm of outdoor and exhaust air, while recovering some of the energy used to heat or cool the indoor air. Because of the low humidity in the Las Vegas area, the unit's energy wheels were supplied without a desiccant.

Testing Protocols and Measurement Methods

Monitoring was conducted at the two schools for two one-week summer periods in July and September, while the ERVs were cycled on and off. Four days of ERV "On" and four days of ERV "Off" data were collected from each school. Locations for testing/monitoring included those in each of the four classrooms, and in the outdoor air at each school. Testing consisted of monitoring a number of pollutants, measuring flow rates, ventilation rates, temperatures and relative humidity, and observing classroom activities. A description of the various measurement and testing methods is given in Table 1 for review.

RESULTS AND DISCUSSION

Thermal Comfort

Prior to the project and during the first week of testing, many teachers at School A mentioned that their classrooms became uncomfortably warm during the afternoon when outdoor temperatures rose above 100^{o} F. An inspection of the HVAC equipment found that the cooling coils were almost completely obstructed with dirt. As a result, the cooling efficiency of the existing HVAC units in both rooms at School A was improved when the cleaning was performed after the initial week of testing. With outdoor air temperatures relatively constant, indoor temperatures were reduced from 5 to 7^{o} F after the cleaning. As a result, the classrooms were noticeably more comfortable during the follow-up weeks of testing. The improvement in cooling efficiency is a function of the cleaned cooling coils (thus better heat transfer) and increased airflow through the system (due to less obstruction in coils). Investigators were not able to conduct airflow measurements prior to the cleaning to enable comparison of before and after airflow volumes.

At School B, the cleaning had no observable impact on indoor temperatures. This is probably because these rooms had excess cooling capacity available with the auxiliary window units that can be activated by the teachers as indoor temperatures increase.

ERV Operation:

Some calculations of ERV efficiency are simply based on the energy recovered by the energy exchange element (heat wheel). Those efficiency values were computed, including the heat gain from the motors, to average 0.69 (School A) and 0.58 (School B) for periods of 25 and 23 hours, respectively. However, when the total energy balance for the ERV's systems at the two schools was evaluated, it was found to be dominated by the power required by the fan and heat wheel motors (approximately 1400 W. total). As a result, for much of the monitoring period (when outdoor temperatures were higher than indoors), the energy rejected from the hot incoming air was less than that required to operate the ERV motors, causing negative overall efficiencies.

Ventilation and Pollutant Measurements

Table 2 summarizes averages for the ERVon/ERV off testing periods. A brief synopsis of each of the measurements is presented here for review.

Ventilation rates:

Ventilation rates prior to ERV installation were low in all classrooms studies ranging from 0.2 ach at School A to approximately 0.7 ach at School B. Operation of the ERV's increased ventilation rates by a factor of approximately 15 in School A and 5 in School B. ERV operation also afforded adequate ventilation (in excess of 15cfm/person) in accordance with ASHRAE Std. 62-1989 (1).

Carbon Dioxide:

Average school day indoor CO_2 concentrations without ERV's often exceeded 3,000 ppm at School A, and 1,500 ppm at School B. Maximum concentrations at School A were greater than 5,000ppm. These levels are not an uncommon occurrence in the high occupant density environment of schools (2, 3). Although CO_2 concentrations in the control rooms did not demonstrate a significant change when the ERV's were operated, levels in the study room at School A were reduced by a factor of four and by a factor of approximately two at School B.

Particle Mass (PM_{10}) and Particle Counts:

Indoor particle levels in both schools were consistently higher than outdoors. Levels of airborne particles in schools are often found to be elevated compared to outdoors (4) and can be attributed to indoor sources and occupant activity. PM_{10} and particle count averages from Table 2 reveal only a slight decrease in particles as a result of the ERV operation. Due to the few number of data points and the variation in particle levels within the control room on a day to day basis, no definite conclusions can be drawn as to the effect of ERV operation. A study conducted in 38 commercial office buildings showed similar results of no discernible correlation between respirable particles (<3.0μm) concentrations and one-time measurements of ventilation rates among the different buildings (5).

Bioaerosols:

Some generalizations can be made regarding the bioaerosol studies in these 2 schools: 1). Overall bioaerosol levels were very low both indoors and outdoors (particularly due to Las Vegas dry climate); this is notably different from data seen in other school studies throughout the U.S.(6) 2). Viable fungi were especially low both indoors and outdoors. 3). Total spore concentrations were higher than viables indoor and outdoors with many of the spore types present not able to grow or reproduce in culture. One of the most surprising findings from the Burkhard slides was the presence of Myrothecium spores on over 50% of the indoor samples. This suggests an indoor source of the fungus was present at both schools. When the ERV units were tested at both schools, significant amounts of fresh air were introduced to the classrooms. Noting that the overall bioaerosol levels in the schools, and outdoors, were exceptionally low, it was not possible to fully evaluate the ability of the ERV to dilute bioaerosol levels from a "contaminated" indoor environment.

Total Volatile Organic Compounds (TVOCs):

Indoor levels of TVOCs can be very dependent upon episodic releases of pollutants, such as classroom activities involving educational supplies and custodial services that entail the use of cleaning/housekeeping materials. This may explain the widely ranging school TVOC concentrations in all classrooms tested. That the source of TVOCs is located indoors can be seen in Table 2 which displays indoor and outdoor average concentrations. The comparison of TVOC levels between periods with the ERV operating and the ERV off suggests that the additional ventilation with outdoor air (low in TVOCs) causes a reduction in indoor concentrations, particularly at School A. However, this result is not conclusive due to the large day-to-day variations in concentrations and the small size of the data set. On average, indoor concentrations were higher at School A, although with the ERVs operating, the levels in the two study rooms were comparable. The concentrations of TVOCs in four Santa Fe, New Mexico schools ranged from 180 to 2700 μgm^{-3} (7, 8), while the median concentration of TVOCs reported for 198 residences was 700μgm^{-3} (9).

SUMMARY

Ventilation rates in all rooms without ERVs operating were very low, providing only 1.4 to 4.4 cfm/occupant of outdoor air. However, even though the ERV supply rates were less than design specifications, they boosted the outdoor air ventilation rates to almost 21 cfm/occupant in the two study rooms -- well above ASHRAE's recommendation of 15 cfm/occupant. Indoor levels of CO_2 were much higher than ASHRAE's recommendation of 1000 ppm -- occasionally exceeding 5000 ppm (prior to ERV installation). In both study rooms, operation of the ERVs caused average indoor concentrations to be reduced below 1000 ppm.

Thermal comfort in the two rooms at School A was improved when school day temperatures were reduced from 5 to 7°F after the cooling coils in the HVAC units were cleaned..

Overall bioaerosol levels were very low both indoors and outdoors in the schools. Due to the low concentrations of viable and nonviable spores in the classrooms, it was not possible to fully evaluate the ability of the ERV to dilute bioaerosol levels from a "contaminated" indoor environment.

The effect of ERV operation on particle levels is inconclusive due to the small number of data points attained in the study. The day to day variances related to classroom activity and source emissions, combined with the variance in particle levels noted within the control rooms (no ERV in the control rooms), makes it impossible (without more on-site study) to clearly define the effect of the dilution air on resultant classroom particle concentrations.

Indoor concentrations of TVOCs varied widely during the test periods, but were usually within the range reported for other indoor environments. The data collected here suggest that indoor levels in the study rooms were reduced with the introduction of additional outdoor air, yet the results are not conclusive.

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KEY WORDS

Carbon Dioxide
Particles
Schools
TVOC
Ventilation

Table 1. Summary of IAQ Measurements.

Type	Locations	Duplicate Samples	Frequency	Instrumentation	Method of Analysis
CO_2	2 Rooms Outdoors	N/A	Continuous	Riken RI-411	Non Dispersive Infrared Spectometry
Temp/RH	2 Rooms Outdoors	N/A	Continuous	Campbell Scientific Model 207	Thermistor/Capacitive humidity Sensor
Ventilation	2 Rooms	N/A	2/Day	B&K 1302 Multi-gas Analyzer	Tracer Decay (ASTM E741-93)
PM10	2 Rooms Outdoors	Study Room	1/Day	Air Diagnostics &Engr. PM10 Impactor	Gravimetric for <10 micron Particles
Particle Counts	2 Rooms Outdoors	Control Room	Continuous	Climet CI-4100	Laser Diode Particle Counter
TVOC	2 Rooms Outdoors	Study Room Outdoors	1/Day	Mulitsorbent Sampling Tubes	Flame Ionization Detection or GC/MS
Viable Fungal	2 Rooms Outdoors	2 Rooms Outdoors	3/Day	Anderson N-6 Sampler	Sieve Impaction on Culture Plates
Total Spores	2 Rooms Outdoors	2 Rooms Outdoors	3/Day	Burkhard Volumetric Air Sampler	Particulate Impaction
Radon	2 Rooms	N/A	Continuous	Niton Rad-7	Electrostatic Collection of Alpha Emitters

Table 2. Summary of IAQ Measurement Averages.

		VENTILATION RATES (ACH)		CARBON DIOXIDE (ppm)		PARTICLE MASS (PM-10) ($\mu g/m^3$)		PM-10 AVERAGE OF DAILY RATIOS STUDY ROOM/CONTROL		PARTICLE COUNTS ≥0.5µm (MILLIONS p/m^3)		PARTICLE COUNTS >0.5µm AVERAGES OF DAILY RATIOS OF STUDY ROOM/CONTROL	
		ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF
SCHOOL A	Study Room	2.9	0.2	860	3030	67	76	0.42	0.42	6.28	8.63	0.36	0.48
	Control Room	0.2	0.2	2910	3110	160	180	-	-	17.89	19.37	-	-
	Outdoors	-	-	380	380	21	25	-	-	2.55	4.26	-	-
SCHOOL B	Study Room	3.3	0.7	890	1710	44	50	0.96	1.00	4.80	4.93	1.18	1.19
	Control Room	0.7	0.7	1830	1500	47	51	-	-	4.09	4.23	-	-
	Outdoors	-	-	350	320	35	25	-	-	4.86	4.53	-	-

Table 2. Summary of IAQ Measurement Averages continued -

		BIOAEROSOLS TOTAL SPORES (Spores/m^3)		BIOAEROSOLS (TOTAL SPORES) AVERAGES OF DAILY RATIOS STUDY ROOM/CONTROL ROOM		BIOAEROSOLS VIABLES (CFU/m^3)		BIOAEROSOLS (VIABLES) AVERAGES OF DAILY RATIOS STUDY ROOM/CONTROL ROOM		TVOC CONCENTRATION ($\mu g/m^3$)		TVOC AVERAGES OF DAILY RATIOS OF STUDY ROOM/CONTROL	
		ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF	ERV ON	ERV OFF
SCHOOL A	Study Room	934	624	0.99	0.88	61	86	0.55	1.15	766	1780	0.63	0.62
	Control Room	504	761	-	-	113	95	-	-	1980	4220	-	-
	Outdoors	1583	3139	-	-	133	184	-	-	187	142	-	-
SCHOOL B	Study Room	669	744	0.98	1.14	59	54	1.19	1.16	417	815	0.38	0.77
	Control Room	704	729	-	-	48	46	-	-	1420	1250	-	-
	Outdoors	3580	2406	-	-	268	92	-	-	142	213	-	-