Fan Pressurization of School Buildings

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ABSTRACT

In the past two years, a substantial number of schools in the United States have been tested for radon. In some of them, radon levels were found to be elevated above the Environmental Protection Agency (EPA) action level of 4 pCi/L. In response to this situation, the EPA School Evaluation Program investigated 30 schools, all of which had elevated radon levels. When building pressurization seems a possible and appropriate response for the control of indoor radon, the tightness of the building shell is estimated. This was done in several of the school buildings in the sample. Pressurization or depressurization of the buildings is accomplished using one or two calibrated fan doors and/or existing HVAC exhaust or outdoor air fans. The data are analyzed in terms of air exchanges at 25 pascals and cubic meters per minute of airflow normalized to a square meter of exposed surface area. Leakage sites are visually characterized. The data set is compared to data collected by Persily and Grot (1986) in seven federal office buildings.

INTRODUCTION

The Environmental Protection Agency undertook a program to investigate school buildings with elevated radon levels in 1989. This program has continued into 1992. It is known as the School Evaluation Program (SEP) and is part of the radon efforts from the Office of Radiation Programs. School investigations in this program collected information to answer three questions (Brennan et al. 1990). First, can the radon levels be reduced enough if the school ventilation rates met guidelines (current or those in existence at the time of school construction)? Second, what kind of soil depressurization system would be needed to control the radon levels in the school? Third, how much outdoor air must be provided to the school in order to pressurize it enough to keep soil air out? The last question cannot be answered without measuring the airflow-pressure difference characteristics of the building shell. When it was possible to do so, these data were collected for schools in the SEP. The information was collected in 13 schools. This paper reports the results of those measurements and compares them to similar measurements made in office buildings.

PROCEDURE

Researchers have used fan pressurization techniques to investigate the leakage characteristics of buildings since the mid-1970s. The methods developed and documented in previous work were applied to this study (Brennan 1989; Persily and Grot 1986; Sherman and Grimsrud 1980: Shaw et al. 1973). The schools were from one to three stories in height. Floor areas ranged from 8,550 ft^2 (794 m^2) to 300,000 ft^2 (27,872 m^2). All schools were brick or brick veneer on hollow core masonry construction.

All doors, hatches, and windows were closed in the building. Outdoor air dampers were closed. Air was exhausted from the schools at several different flow rates using fan doors, existing exhaust fans, or a combination. The airflow volumes and the air pressure difference across the building shell to the outdoors were measured. The indoor/outdoor air pressure difference was measured using a varying capacitance micromanometer. The airflow through the fan door was calculated from the measured pressure drop across the fan door flow nozzle. The airflow through exhaust fans was calculated from the pressure drop across the upstream and downstream sides of a flow grid in a calibrated flow hood.

The data were analyzed by fitting them to an equation of the form

$$Q = C\Delta P^n \tag{1}$$

where

Q = airflow (cfm [m^3/h]),
C = flow coefficient ($ft^3/min \cdot Pa^n$ [$m^3/h \cdot Pa^n$]),
n = flow exponent (unitless),
ΔP = pressure difference (Pa).

Two figures of rank were calculated to attempt a comparison of buildings with very different floor areas and shapes. The curve-fit equation was used to calculate air changes per hour at 25 pascals air pressure difference (ach @ 25 Pa) and cubic meters per hour per square meter of exposed surface area of the building at 25 pascals ($m^3/h \cdot m^2$ @ 25 Pa). Roof areas were included in the surface area calculation.

DISCUSSION

The leakage characteristics of the school building shells are comparable to those of office buildings reported by Persily and Grot (1986). Figure 1 compares the two figures of rank for office buildings and schools using box plots. A box plot gives a sense of central tendency (the heavy horizontal line in the box is the median), deviation (the top

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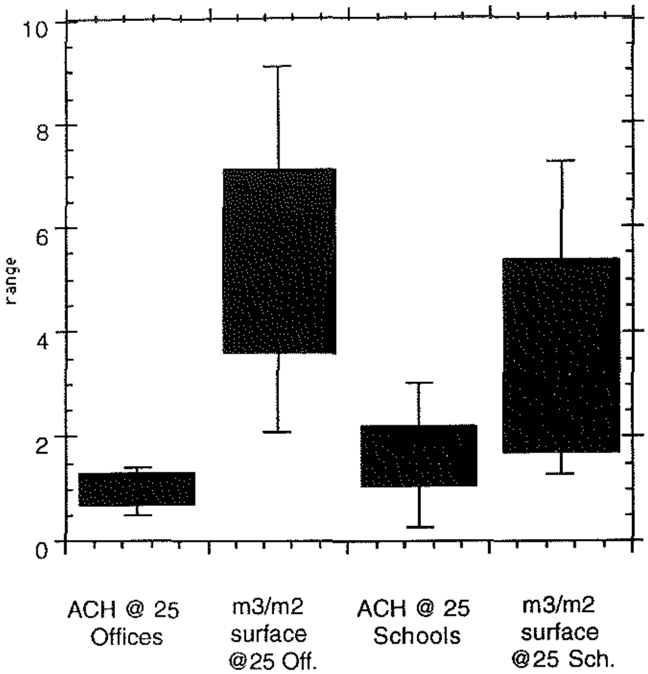

Center lines are medians, each box encloses half the data points (±25%) and the error bars represent the high and low values.

Figure 1 *Shell tightness of schools and office buildings.*

and bottom of the box marks ± 25% of the population, so the box encloses 50% of the data points), and range (the error bars at the top and bottom show the maximum and minimum data points). By either normalized measure, the 13 schools have a wider range of airtightness values than the seven office buildings.

Table 1 lists the building's name, surface area, floor area, surface-to-volume ratio, flow coefficient (C), flow exponent (n), effective leakage area, ach @ 25 Pa, $m^3/h{\cdot}m^2$ @ 25 Pa, and the ratio of $m^3/h{\cdot}m^2$ to ach @ 25 Pa. The first seven buildings are office buildings from Persily and Grot (1986). The second 13 buildings are all schools from the SEP. The means and standard deviation of each variable are listed at the bottom of each data set. While the largest school has greater floor area than all the office spaces but one, the schools are generally smaller buildings.

The mean school floor area is around 53,900 ft^2 (5,000 m^2) and the mean office floor area is more than three times as large, nearly 183,000 ft^2 (17,000 m^2). The effective leakage area (ELA @ 4 Pa) is shown for each building. The mean ELA for office buildings is 3,972 $in.^2$ + standard deviation (STD) of 3,220 (25,623 cm^2 + STD of 20,777). The mean ELA for schools is 1,362 $in.^2$ + STD of 1,883 (8786 + STD of 12,146 cm^2). The ELA is not very good for comparing the leakage of buildings of vastly different size. Leakage area is more a function of exposed surface area than of building volume. So, leakage areas three times smaller in schools that are three times smaller in floor area than office buildings are not unexpected.

Normalizing the airflow at 25 Pa to the surface area of the building seems to give comparable results between office and school data sets. The offices have a mean of 5.54 $\pm$ 2.4 $m^3/h{\cdot}m^2$ @ 25 Pa and the schools have a mean of 4.18 $\pm$ 2.1 $m^3/h{\cdot}m^2$ @ 25 Pa. Normalizing the leakage to ach @ 25 Pa, however, does not produce such comparable results. The offices have a mean of 0.9 $\pm$ 0.33 ach @ 25 Pa and the schools have a mean of 1.6 $\pm$ 0.9 ach @ 25 Pa. Using the leakage rate normalized to the surface area of the buildings as a yardstick, school buildings are slightly tighter than offices. The tightest schools are significantly tighter than offices, the tightest two office buildings having 2.1 and 3.6 $m^3/h{\cdot}m^2$ @ 25 Pa and the tightest three schools having 1.3, 1.51, and 1.7 $m^3/h{\cdot}m^2$ @ 25 Pa. When interpreting these data, it should be remembered that the shape of the building may be important. The surface area of tall buildings is less impacted by roof area than that of low-rise buildings of equal floor area. Roofs in schools and office buildings are usually flat, membrane-covered roofs with low leakage areas. Schools may appear tighter because a higher percentage of surface area is in the roof.

Normalizing the airflow at 25 Pa to the building volume, ach/h @ 25 Pa, makes the office buildings appear much tighter than the school buildings. The office buildings have a mean of 0.91 ach/h @ 25 Pa $\pm$ STD of 0.33 and the schools have a mean of 1.59 ach/h @ 25 Pa $\pm$ STD of 0.85. Smaller buildings are expected to have larger air changes per hour because of the comparatively larger surface area. Although the floor area of the offices is about three times larger than that of the schools, the surface area is only two times larger.

Table 2 lists the mean, standard deviation, and relative variation for each data set. The relative variation presents the standard deviation as a percent of the mean. This allows a more direct comparison of variation of different data sets with different units. There is less variation within the office building data than within the school data.

CONCLUSION

The tightness of school building shells is comparable to that of office buildings. Normalizing the airflow @ 25 Pa by surface area seems to be a reasonable method for comparing the larger office buildings to smaller school and office buildings. Differences in the shapes of low-rise and high-rise buildings have an impact on the normalized airflows. A larger data set than is currently available would need to be examined and compared with a geometric analysis before the impact could be quantified. For example, the surface-to-volume ratios of smaller buildings are generally larger than for bigger buildings. A multi-story building that is shaped like a cube has a smaller surface-to-volume ratio than a building of the same floor area that is spread out over several wings on one story.

TABLE 1
The Airflow-Pressure Difference Characteristics of School/Office Buildings

Building	Surface Area (m^2)	Floor Area (m^2)	C ($m^3/h \cdot Pa^n$)	n	ELA @4 Pa (cm^2)	ach @25 Pa	m3/h•m2 Surface @ 25 Pa	$m^3/h \cdot m2$ /ach @ 25 Pa
Office Buildings								
Anchorage	23000	48470	21400	0.61	53665	0.75	6.8	9
Ann Arbor	6630	5270	3170	0.67	8639	0.8	.4.1	5
Columbia	13800	21600	18300	0.47	37795	0.7	6	9
Huron	6620	6910	1580	0.64	4130	0.5	2.1	4
Norfolk	12100	18520	8080	0.74	24264	1.4	7.1	5
Pittsfield	2300	1860	2550	.036	4522	0.95	3.6	4
Springfield	8940	14560	99	2.09	1932	1.3	9.1	7
Mean	10484	16741	7883	0.80	19278	0.91	5.54	6.12
STD	6701	15748	8585	0.58	20048	0.33	2.4	2.11
Schools								
Albany	27872	22297	15459	0.70	44163	2.2	5.35	2
Administration	5853	8194	2564	0.34	4410	0.3	1.3	4
Argentine	794	688	533	0.63	1372	1.33	5.08	4
Bishop Ryan	6875	5574	1602	0.82	5338	1.3	3.21	2
CLC	3270	4645	449	0.75	1358	0.35	1.51	4
Green Mountain	2027	2369	2732	0.46	5565	1.39	5.93	4
Grn. Mtn. Gym	1672	929	2232	0.52	4955	2.12	7.17	3
Laurel	3468	1517	1828	0.44	3607	1.08	1.7	2
Middle School	9142	7172	9390	0.61	23451	3.03	7.24	2
S. Pines	5704	4422	860	0.76	2647	0.73	1.73	2
S. Tama - Gym	1301	650	1038	0.50	2241	2.64	4.03	2
Russell	4181	3252	907	0.99	3874	2.24	5.32	2
Velva	6875	5574	4372	0.63	11240	1.94	4.8	2
Mean	6080	5176	3382	0.63	8786	1.59	4.18	2.90
STD	7016	5708	4336	0.18	12146	0.85	2.12	1.00

TABLE 2
Relative Variation

Data Set	Mean	Standard Deviation	Relative Variation%
ACH @ 25 offices	0.91	0.33	36
ACH @ 25 schools	1.59	0.85	53
m3/m2-hr@ 25 offices	5.54	2.4	43
m3/m2-hr@ 25 schools	4.18	2.12	51

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