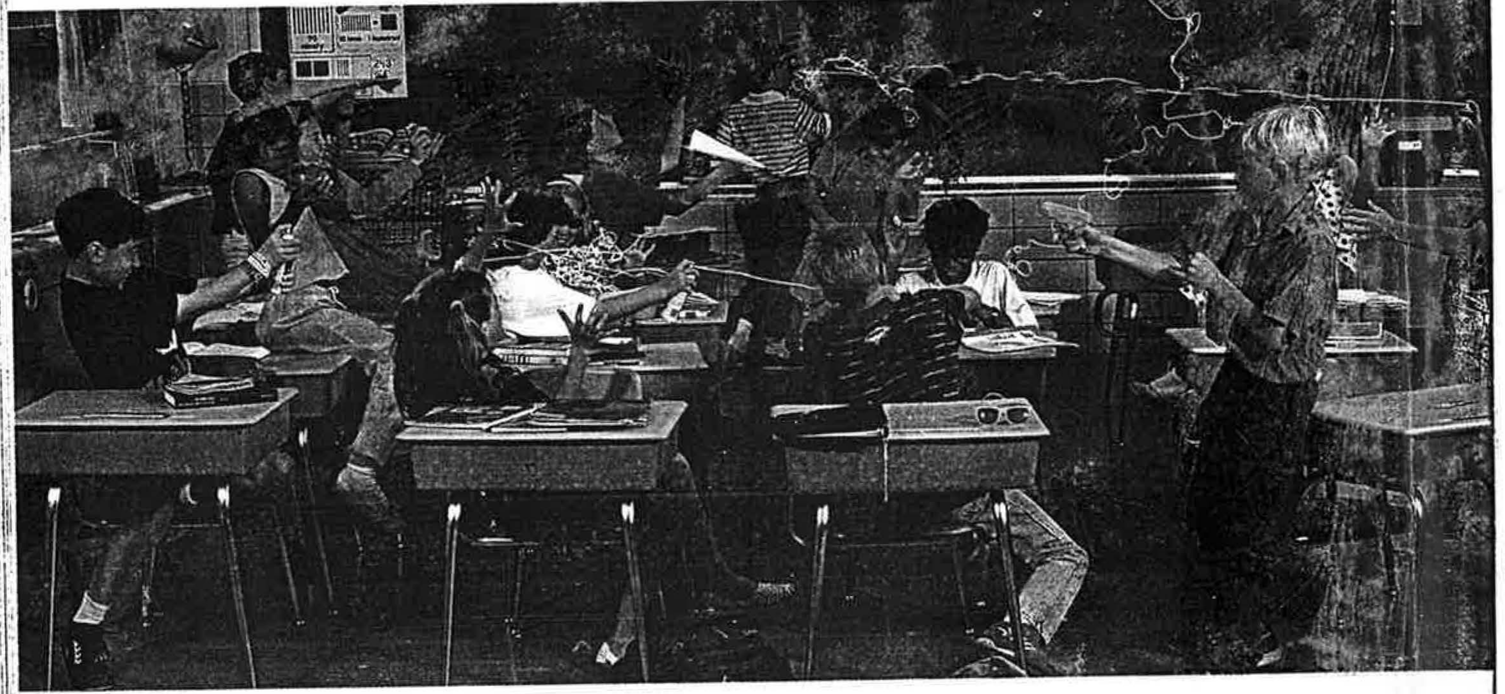

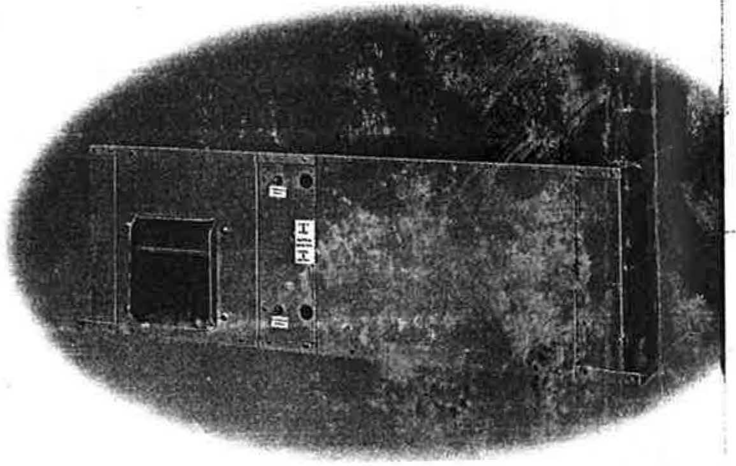

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Taking a New Look At School Ventilation

Maine school shows how ever-improving building-envelope construction and changes in building loads makes "fresh-air" cooling increasingly attractive

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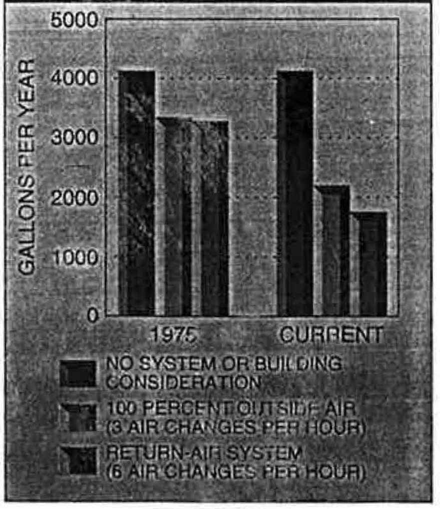
Over the past 20 years, classroom loads have shifted from heating and cooling to predominantly cooling. This shift is, in large part, because of improved building envelopes that have effectively reduced heat loss within the buildings.

As illustrated in the following case study, the general effect of this trend has been to:

- Reduce ventilation fuel requirements by approximately one half.
- Double the amount of "fresh-air" cooling needed to prevent overheating.
- Increase ventilation fuel requirements of 100 percent outside air systems relative to return-air systems.
- Change the relative efficiencies and effectiveness of many typical school ventilation systems.

The 24-classroom school used in the study is a single-story building in Bangor, Maine. Key energy-use data are summarized in Table 1. The case study compares the building with a hypothetical building from 1975 with identical parameters except that the 1975 building has heat-transfer coefficients of 0.09 Btu per hour per square foot per degree Fahrenheit for the roof, 0.30 for for walls and 1.13 for windows.

FIGURE 1—**VENTILATION FUEL REQUIREMENTS**



Ventilation fuel requirements for school buildings have decreased dramatically since 1975, particularly for return-air systems.

Today's reduced ventilation

Ventilation loads normally are calculated using the following formula:

$$Q = 1.085 \times CFM \times (T2-T1)$$

where:

Q=ventilation load (Btu per hour).

CFM=outside air (cubic feet per minute).

T2=room temperature (degrees Fahrenheit).

T1=outside air temperature.

1.085=constant conversion factor for standard air.

On the surface, this formula appears to be independent of building construction, and it is, as long as the building is in a heating mode. However, once the classroom switches to a cooling mode, T2 must be reduced to overcome the net heat gain within the room. As insulation levels have increased, net heat gains have become larger. This, in turn, has lowered supply-air temperature and reduced ventilation-fuel use.

Figure 1 shows the theoretical maximum amount of fuel required for the Maine school with a T2 of 70°F, as well as requirements using a 100 percent outside-air system and a return system. Without taking net heat gains into account, the theoretical maximum amount of fuel required using the above formula is 4,100 gallons per year. However, taking into account the net heat gains for a system providing six air changes per hour, fuel requirements in the modern-day building drop to 1,864 gallons per year.

In order to gain this magnitude of savings, net cooling loads must be prevalent throughout the entire school year. In this particular example, a typical classroom requires cooling during an average January day, even with the lights off and the shades drawn.

Comparing ventilation systems

Improved building envelopes have lowered the efficiency of 100 percent outside air systems relative to return-air systems. These 100 percent outside-air systems, by definition, provide minimal airflow to comply with ventilation codes. These minimal rates require lower supply temperatures to compensate for excessive heat gains.

For example, in March, the net heat gain in the Bangor school requires a supply-air temperature of

Heat must be added because design limits room supply to 55°F

49.5°F. Because conventional design limits room supply to 55°F, heat must be added, even though the lost cooling will be detrimental in maintaining room temperature.

With a return system supplying six air changes per hour, the necessary supply temperature is 59.8°F, well above the low limit. The reduction in fuel consumption in this instance is 27 percent. Over the course of a school year, the return system in the modern building uses 325 gallons less than the 100 percent outside-air system.

As shown in Figure 1, the relative efficiency differences have become more pronounced with building-envelope improvements. In fact, any system parameter that increases the ratio between heat gain and heat loss will widen the gap in fuel use between the two systems. Obviously, specific results will vary based on local conditions.

A Breath of Fresh Air

More fresh air is needed in today's schools to offset larger net heat gains. Figure 2 shows the average cubic feet per minute (cfm) required per student for each month of the school year, both for the 1975 construction and the current construction. These outside air quantities are simply satisfying cooling loads and are independent of code requirements.

It appears that all school ventilation systems are affected by the shift to larger cooling loads, some negatively and others positively. The degradation in performance of systems includes:

- Increased fuel use and overheated classrooms for 100 percent outside-air systems.
- Increased electricity use for heat pumps with fixed outside air.
- Increased electricity use for variable air volume.

Performance improves for return-air systems that take full advantage of the shift. Benefits of these systems include:

- Good temperature control without mechanical cooling.
- Improved indoor air quality because of higher ventilation rates (as indicated in Figure 2).

Fresh-air cooling is not new. It has been used for years to reduce energy costs in cooling systems. Its use in today's schools is a rare opportunity in many climates to provide all cooling necessary throughout the traditional school year by opening simply a damper.

Heat recovery

The reduction in ventilation-fuel requirements has brought an accompanying decrease in the effectiveness of heat-recovery systems for schools like the one studied. It is not that there is any less heat in the exhaust stream, but rather there is less need to recover heat.

In the case study, efficiencies of 40 percent through 100 percent were used in comparing central station systems with and without heat recovery. The air-handling systems are constant volume supplying 17,200 cubic feet per minute (cfm) with 50 percent outside air.

Table 2 shows net savings of both fuel and electricity for the several heat-recovery-system efficiencies. Even with high efficiencies, simple payback periods would be unreasonably long.

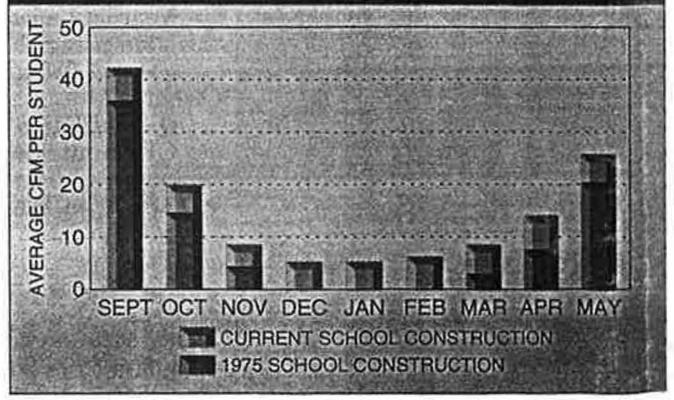
Variable air volume

Envelope improvements have reduced savings associated with variable air volume in many school applications. First, as mentioned, higher airflow rates are now required to satisfy larger net heat

TABLE 1—**KEY ENERGY DATA**

STUDENT DENSITY	3 PER 100 SQUARE FEET
LIGHTING LOADS	1.65 WATTS PER SQUARE FOOT
HEATING SYSTEM EFFICIENCY	70 PERCENT
VENTILATION SCHEDULE	8 HOURS PER DAY, 180 DAYS PER YEAR
FUEL COSTS (#2 FUEL OIL)	$0.70 PER GALLON
ELECTRICITY RATES (INCLUDING DEMAND)	$0.12 PER KILOWATT-HOUR
HEAT-TRANSFER COEFFICIENTS (BTU PER HOUR PER SQUARE FOOT PER DEGREE FAHRENHEIT)	
ROOF	0.034
WALLS	0.052
WINDOWS	0.34

FIGURE 2—
FRESH-AIR COOLING REQUIRED



Modern-construction school buildings often require cooling even in the dead of winter. In the study, a typical classroom requires cooling during an average January day, even with the lights off and the shades drawn.

Envelope improvements in school buildings since the mid 1970s have significantly changed the dynamics of school ventilation

TABLE 2—**HEAT-RECOVERY SAVINGS**

HEAT RECOVERED (PERCENT)	60	70	80	90	100
ANNUAL SAVINGS (DOLLARS)	199	330	460	591	721

TABLE 3—**VARIABLE-AIR-VOLUME SAVINGS**

AIR CHANGES PER HOUR	4	5	6	7	8
ANNUAL SAVINGS ($)	-65	$183	$432	$661	$854

gains. It might be added that minimum airflow rates are limited to classroom ventilation needs.

In this case study, for example, the total airflow is six air changes per hour, with half of that needed for ventilation. Second, at minimum flows, the system functions as a 100 percent outside-air unit with the penalties described earlier.

These factors diminish the relative cost-effectiveness of this approach. Table 3 lists annual savings for a variable-air-volume system versus constant volume at four through eight air changes per hour. Once again, simple payback periods for the case study were not acceptable.

Hydronic heat-pump system

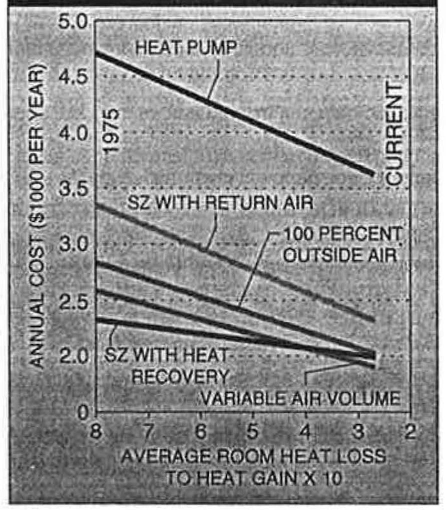
Heat-pump systems are afflicted by some of the inefficiencies associated with systems discussed earlier. First, there is the penalty of having to heat outside air to some predetermined setpoint. For 100 percent outside-air units it is the low-limit setting. For heat pumps it is the minimum entering-air temperature.

In the case study, outside air is preheated with loop water to 55°F. (Loop water is heated either by heat pumps in the cooling mode or by a boiler.) When mixing this air with return air, the resulting temperature often is above the necessary supply temperature, thus requiring mechanical cooling. In the case study, the cooling energy needed is 8,370 kilowatt-hours from September through May. Raising the entering-air temperature to 60°F increases the required cooling energy by 64 percent and total operating costs by $600.

Second, as in the case of heat recovery, fan energy increases because of higher static pressures resulting from the addition of a preheat coil. In the case study, heat-pump fan energy exceeds that of a return system by 2,500 kilowatt-hours. If a precooling coil also is required, that differential increases to 6,500 kilowatt-hours for the school year. Because only loads associated with the traditional school year are being considered in this analysis, precooling-coil pressure drops are not included.

Finally, there is an inefficiency unique to heat pumps. This can best be seen when all heat gains are gone and the system is in the heating-only mode. Here, as with all systems, fuel use is 4,100 gallons per year. Heat pumps, however, require as much as 10,000 kilowatt-hours per year to extract the required heat from the loop water. In the actual case study, this penalty is reduced to 200 kilowatt-hours per year, and fuel use is 1,806 gallons per year. As indicated in Figure 3, operating costs for the hydronic heat-pump system were the highest of any of the systems considered.

FIGURE 3—
FUEL AND ELECTRICITY



Operating costs for the variable-air-volume system were lowest in the study. A hydronic heat pump had the highest associated energy cost.

Summary

Envelope improvements since the mid-1970s have significantly changed the dynamics of school ventilation. When estimating ventilation fuel use, the effects of all system parameters on the traditional ventilation loads formula must be considered.

These changes, in turn, have had an impact on both the effectiveness and efficiency of mechanical ventilation systems. Newer and more costly ventilation systems may not provide better indoor air quality or cost-effective energy savings in these applications. A closer look may be necessary in making an accurate evaluation of ventilation-system performance. ☐

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