Using Dedicated Outdoor Air Systems

Economics of Improved Environmental Quality

By Stanley A. Mumma, Ph.D., P.E.
Fellow ASHRAE

Table 1: Building design data.

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Unit Cost</th>
<th>Units VAV with TER</th>
<th>Units DOAS</th>
<th>Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller</td>
<td>$1,000/ton ($284/kW)</td>
<td>350 ton (1230 kW)</td>
<td>306 ton (1076 kW)</td>
<td>$44,000</td>
</tr>
<tr>
<td>Chilled Water Pump</td>
<td>$25/gpm ($400/L/s)</td>
<td>850 gpm (53.5 L/s)</td>
<td>737 gpm (46.4 L/s)</td>
<td>$2,830</td>
</tr>
<tr>
<td>Ductwork</td>
<td>$1/ft² ($11/m²)</td>
<td>DOAS 4/ft² ($43/m²)</td>
<td>VAV</td>
<td>186,000 ft² (17,300 m²)</td>
</tr>
<tr>
<td>AHU</td>
<td>$2/cfm ($4.25/L/s)</td>
<td>VAV 4/ft² ($8.50/L/s)</td>
<td>DOAS 186,000 ft² (17,300 m²)</td>
<td>$306,000</td>
</tr>
<tr>
<td>Electrical Serv.</td>
<td>$50/kW</td>
<td>425 kW</td>
<td>372 kW</td>
<td>$2,650</td>
</tr>
<tr>
<td>Façade/Partitions</td>
<td>$35/ft² ($376/m²)</td>
<td>No depth reduction</td>
<td>1 ft (0.3 m) Plenum Depth/Floor or 4308 ft² (400 m²)</td>
<td>$150,780</td>
</tr>
<tr>
<td>Integrated Thermal and Fire</td>
<td>$0.65/ft² ($7/m²)</td>
<td>Savings</td>
<td>NA</td>
<td>186,000 ft² (17,300 m²)</td>
</tr>
<tr>
<td>Drop Ceiling</td>
<td>$1.50/ft² ($16/m²)</td>
<td>NA</td>
<td>79,200 ft² (7,365 m²)</td>
<td>$118,800</td>
</tr>
<tr>
<td>Mechanical Shaft Impact on</td>
<td>$125/ft² ($1344/m²)</td>
<td>NA</td>
<td>500 ft² (47 m²) saved</td>
<td>$62,500</td>
</tr>
<tr>
<td>Radiant Panel</td>
<td>$13/ft² ($140/m²)</td>
<td>NA</td>
<td>79,200 ft² (7,365 m²)</td>
<td>$1,029,600</td>
</tr>
<tr>
<td>Net Savings</td>
<td>$336,860 or $1.81/ft² ($19.47/m²)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: First-cost comparison of the DOAS vs. a conventional all-air VAV system with total energy recovery serving a six-story, 186,000 ft² (17 300 m²) building in Philadelphia.

The thermodynamic, indoor air quality (IAQ) and thermal comfort performance of an integrated dedicated outdoor air (DOAS) radiant ceiling panel cooling system were addressed in previous issues of IAQ Applications. An economic analysis of DOAS in ASHRAE Journal compared the DOAS using total energy recovery (TER) with a conventional all-air variable air volume (VAV) system without TER. This has since been questioned by some as an “unfair” comparison. That topic will be one of the following three economic issues addressed here:

- A cost comparison of the DOAS with a conventional VAV system using TER.
- The economic impact of delivering more than the minimum ventilation air with the DOAS.
- Influence of interest, inflation, and corporate taxes on design and investment decisions.

Comparing DOAS to VAV System Using TER

This comparison, considering both first and operating costs, has not been presented in previous publications for two reasons. First, the use of TER is extremely rare in the author’s experience. And second, TER is not required by ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, for VAV systems, but is required for systems over 5,000 cfm (2360 L/s) that uses more than 70% outdoor air (OA). The work that follows will explore the economics that may explain the observed design practices that generally do not couple TER with VAV systems. It should not be inferred that the coupled systems are never used or are not required by some local codes.
Table 3: Operating cost comparison, DOAS vs. a VAV system with total energy recovery. The utility rate used to develop the data is: demand block 1: 200 kWh/kW, $0.065/kWh; demand block 2: 200 kWh/kW, $0.052/kWh; demand block 3: remaining kWh, $0.05/kWh. Demand charge is $6.94/kW.

<table>
<thead>
<tr>
<th>System</th>
<th>Annual Mechanical Operating Cost</th>
<th>Annual Total Mechanical, Illumination &amp; Equipment Operating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAV with TER</td>
<td>$80,860</td>
<td>$300,870</td>
</tr>
<tr>
<td>DOAS</td>
<td>$59,730</td>
<td>$273,565</td>
</tr>
<tr>
<td>Annual Savings</td>
<td>$21,130</td>
<td>$27,305</td>
</tr>
<tr>
<td>$/ft² ($/m²)</td>
<td>$0.11 ($1.22)</td>
<td>$0.15 ($1.58)</td>
</tr>
<tr>
<td>Annual Cost Ratio, VAV with TER (Integrated System)</td>
<td>1.35</td>
<td>1.10</td>
</tr>
</tbody>
</table>

First-Cost Analysis

A first cost analysis of the two mechanical alternatives (DOAS vs. VAV with TER) applied to a six-story brick facade building (see Table 1), 31,000 ft² (2883 m²) per floor, office building in compliance with Standard 90.1, located in Philadelphia, is presented in Table 2.

Using TER in the VAV system brought the design chiller load down from 506 tons (1789 kW) without TER² to 350 tons (1230 kW). Although this is a significant reduction in chiller load, it is not as low as the 306-ton (1080 kW) chiller capacity needed for the DOAS. The higher minimum OA flow rate required with the VAV system plus the added pressure drop of the TER caused the chiller size differential. The chiller first cost reduction, achieved by using the TER preconditioning unit, is almost completely offset by the increase in the first cost of adding the TER OA preconditioning equipment. The DOAS first cost is $1.80/ft² ($19.50/m²), or $336,860 less than the VAV system with TER. The VAV system first cost with TER is about $38,800 lower than the VAV system without TER but still more expensive than the DOAS.

Operating Cost Analysis

An hourly energy analysis, for 12 hours-a-day, five days-per-week, was performed for the 186,000 ft² (17 300 m²) Philadelphia building. A VAV system with TER and the DOAS were analyzed. This analysis was performed using existing load and energy analysis software. The results of the simulations are presented in Table 3.

Like the first-cost analysis, the operating cost data favor the DOAS. The mechanical system annual operating cost savings is $21,130 or about $0.11/ft² per year ($1.22/m² per year). Due to the smaller DOAS mechanical plant, the building demand charges were smaller, resulting in an annual building operating cost savings of $27,305, or about $0.15/ft² per year ($1.58/m² per year). It cost about 35% more to operate a conventional VAV system with TER each year than the DOAS. Using the TER in a VAV system reduced the annual chiller plant operation by about $3,000 per year compared to a VAV system without TER. Unfortunately, that savings was more than offset by an increase in the fan operating costs brought about by the added pressure drop of the enthalpy wheel. This analysis did not provide for a bypass of the TER system during the economizer mode, a design practice intended to reduce the fan operating costs during a portion of the year.

Apparently, the modest first-cost savings realized by the TER system in the VAV systems are not sufficiently attractive to building developers and owners.

Economic Impact of Delivering More than Minimum Ventilation Air with DOAS

This section is based upon the hypothesis that the required sensible cooling required of the radiant panels could be reduced by increasing the cold and dry ventilation air supplied to the space, thus reducing the first cost of the radiant panels. Modest increases in the OA flow rate do not impact the chiller plant size appreciably because of the TER incorporated into the DOAS unit. However, it will increase the size of the DOAS and associated ductwork, and the fans’ operating cost. Using the same building and cost data as presented, the impact of increasing the OA from 25,000 scfm (13.85 kg/s) to 30,000 and 35,000 scfm (16.6 and 19.4 kg/s) were explored. The results are presented in Table 4.

As expected, the first cost of the radiant panels dropped by about $80,000 for each 5,000 scfm (2.8 kg/s) increase in OA
Interest, Inflation and Corporate Taxes

When the first cost and the operating cost of an alternative, like the DOAS compared to the VAV system, are both lowest, a life-cycle cost analysis is unnecessary regardless of interest, inflation or taxes. However, with the nearly $30,000 first year energy savings realized with the DOAS, it is instructive to consider the extra first cost that could be justified to break even with an alternative that was more expensive to operate. To get a feel for how interest rate, inflation, and taxes influence the break-even expenditure, Table 5 was developed. The table is by no means exhaustive. The construction of the table is based upon the following assumptions:

- Income tax rate either 50% or no taxes (such as a “not for profit” Public University).
- Interest rates of 4 and 8% compounded annually.
- Inflation rates of 0, 2, 4, 6, and 10% per year.
- Capital equipment depreciated on a straight line basis.
- Length of analysis and depreciation life of the equipment is 20 years.
- Equipment salvage value at the end of 20 years is 20% of first cost.

The break-even first cost of capital equipment was computed using the following equation:

\[ BEFC = PWES - PWLTD + PWTDEP + PWSAL \]

where

- \( BEFC \) = break-even first cost
- \( PWES \) = present worth of energy savings = $30,000 \times \frac{p}{a}
  
  \[
  p/a = \left(\frac{1}{i(1-in)}\right) \times \left(1 - \left(\frac{1}{(1+i)^n}\right)\right), \text{ if } i \neq in
  \]
  
  \[
  i = \text{interest}
  \]
  
  \[
  in = \text{inflation}
  \]
  
  \[
  n = \text{years}
  \]
- \( PWLTD \) = present worth of lost tax deduction from energy savings
- \( PWTDEP \) = present worth of tax savings by straight line depreciation of the equipment
- \( PWSAL \) = present worth of the salvage value after taxes

\[
PWLTD = \frac{30,000 \times \text{tax rate} \times \frac{p}{a}}{\left(\frac{a}{p}\right)}
\]

\[
PWTDEP = \left(\frac{BEFC}{n}\right) \times \left(\frac{p}{a}\right)
\]

\[
PWSAL = \left(\frac{BEFC \times 0.2 \times \frac{p}{f}}{\left(1 + \text{tax rate}\right)}\right)
\]

It is speculated that one of the biggest reasons investors are first-cost minded, rather than life cycle-cost minded is the impact of taxes on the economic analysis. Specifically, consider the impact of lost tax deductions as a result of energy savings. To illustrate, consider the hypothetical situation presented in Table 6.
We think of pollution inside a structure as mostly caused by the materials and contents of the structure itself. But, on Sept. 11, we learned that the materials and contents inside one building can cause indoor pollution inside another building and health problems for their occupants. The destruction of the World Trade Center forces us to reconsider how we guard against indoor pollution, both from an engineering and a legal perspective.

The collapse of the twin towers caused a cloud of dust and debris hundreds of feet high that immediately and violently affected not only the ambient environment but the indoor environments of hundreds of buildings and thousands of offices within a yet-undetermined radius. The thick mist of pulverized cement, insulation, plastic, glass, aviation fuel, and other items was sucked into neighboring buildings through ventilation systems and elevator shafts acting as pistons. It entered offices and homes through windows and doors, even where they were shut. Burning building material and contents soon caused an acrid vapor to wend its way for miles in various directions. The smell lingered, albeit to livable levels, for many weeks after the collapse.

By considering the impact of interest, inflation, and taxes, it is easier to understand why investors generally make their decisions based on first cost rather than life cycle cost.

References

S.A. Mumma, Ph.D., P.E., is a professor of architectural engineering at Penn State University, University Park, Pa. He is an ASHRAE Learning Institute trustee and serves on ASHRAE Technical Activities Committees, Integrated Building Design and Solar Energy Utilization. He can be reached at sam11@psu.edu.