Using Dedicated Outdoor Air Systems

Economics of Improved Environmental Quality

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The thermodynamic, indoor air quality (IAQ) and thermal comfort performance of an integrated dedicated outdoor air (DOAS)[1] radiant ceiling panel cooling system were addressed in previous issues of IAQ Applications. An economic analysis of DOAS in ASHRAE Journal[2] 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.

Floor Plan, Typical All Six Floors	125 × 250 ft (38 × 76 m) Long Axis Pointing E–W
Wall U Value	0.044 Btu/h·ft^2·°F (0.25 W/m^2 ·°C)
Gross Wall Area	67,500 ft^2 (6270 m^2)
Roof U Value	0.03 Btu/h·ft^2·°F (0.17 W/m^2·°C)
Glazing U Value	0.48 Btu/h·ft^2·°F (2.73 W/m^2·°C)
Glazing Shading Coefficients	0.365
Glazing Area	18,000 ft^2 (1670 m^2)
Occupancy	1,250
Overhead Illumination	1.3 W/ft^2 (14 W/m^2)
Task Lighting	0.7 W/ft^2 (7.5 W/m^2)
Equipment Plug Loads	2 W/ft^2 (21.5 W/m^2)

Table 1: Building design data.

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.

Cost Item	Unit Cost	Units VAV with TER	Units DOAS	Cost Savings
Chiller	$1,000/ton ($284/kW)	350 ton (1230 kW)	306 ton (1076 kW)	$44,000
Chilled Water Pump	$25/gpm ($400/L/s)	850 gpm (53.5 L/s)	737 gpm (46.4 L/s)	$2,830
Ductwork	$1/ft^2 ($11/m^2) DOAS $4/ft^2 ($43/m^2) VAV	— 186,000 ft^2 (17 300 m^2)	186,000 ft^2 (17,300 m^2)	$558,000
AHU	$2/cfm ($4.25/L/s) VAV $4/cfm ($8.50/L/s) DOAS	135,000 cfm (73 720 L/s) and 34,000 cfm (16 048 L/s) Preconditioned OA	— 25,000 cfm (11 800 L/s) 100% OA	$306,000
Electrical Serv.	$50/kW	425 kW	372 kW	$2,650
Facade/ Partitions	$35/ft^2 ($376/m^2) of facade	No depth reduction	1 ft (0.3 m) Plenum Depth/ Floor or 4308 ft^2 (400 m^2)	$150,780
Integrated Thermal and Fire Suppression Piping	$0.65/ ft^2 ($7/m^2) savings	NA	186,000 ft^2 (17 300 m^2)	$120,900
Drop Ceiling	$1.50/ ft^2 ($16/m^2)	NA	79,200 ft^2 (7,365 m^2)	$118,800
Mechanical Shaft Impact on Lost Rentable Space	$125/ ft^2 ($1344/m^2)	NA	500 ft^2 (47 m^2) saved	$62,500
Savings Subtotal				$1,366,460
Radiant Panel	$13/ ft^2 ($140/m^2) of panel	NA	79,200 ft^2 (7365 m^2)	– $1,029,600
Net Savings				**$336,860 or $1.81/ft^2 ($19.47/m^2)**

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 ft^2 (17 300 m^2) building in Philadelphia.

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

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.

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 TER[2] 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.

	Reference		
OA flow →	DOAS, 25,000 scfm (13.85 kg/s)	DOAS, 30,000 scfm (16.6 kg/s)	DOAS, 35,000 scfm (19.4 kg/s)
Category	First Cost, $	First Cost, $	First Cost, $
Chiller	306,000	312,000	318,000
Pump	18,415	18,775	19,125
Ductwork	186,000	223,200	260,400
AHU	100,000	120,000	140,000
Elec. Serv.	31,500	31,870	32,240
Acoustical Ceiling	160,200	169,200	178,800
Mechanical Shaft	9,400	11,300	13,200
Radiant Panel	1,029,600	951,600	868,400
First Cost Total for Items Impacted by OA Flow Rate	1,841,115	1,837,945	1,830,165
First Cost Improvement Ref. 25,000 scfm (13.85 kg/s)		3,170	10,950
Annual Mech. Op. Cost	59,730	64,840	65,482
Mech. Op. Cost Penalty, Ref. 25,000 scfm (13.85 kg/s)	0	5,110	5,752
Annual Total Op. Cost	273,565	281,274	282,470
Total. Op. Cost Penalty, Ref. 25,000 scfm (13.85 kg/s)	0	7,709	8,905

Table 4: Impact of increasing the ventilation air with the integrated system on first and operating costs.

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

Additional Break-Even First Cost $	Annual Interest %	Annual Inflation %	Income Tax Bracket %	PW Energy Savings $	PW Lost Tax Deductions $	PW Tax Savings from Depreciation $	PW Salvage Value after Taxes $
448,661	4	0	0	407,709	0	0	40,952
331,685	4	0	50	402,709	(203,855)	112,693	15,138
556,788	4	2	0	482,750	0	0	74,038
454,378	4	2	50	482,750	(241,374)	182,792	30,210
714,286	4	4	0	576,923	0	0	137,363
681,817	4	4	50	576,923	(288,462)	327,797	65,559
960,917	4	6	0	695,542	0	0	265,375
1,231,933	4	6	50	695,542	(347,771)	714,051	170,111
307,749	8	0	0	294,544	0	0	13,205
200,891	8	0	50	294,544	(147,272)	49,309	4,310
436,923	8	4	0	397,423	0	0	39,500
318,648	8	4	50	397,423	(198,711)	105,532	14,404
901,692	8	10	0	665,060	0	0	236,632
1,057,100	8	10	50	665,060	(332,530)	588,862	137,708

Table 5: Additional break-even first cost with an assumed $30,000 energy savings in the first year over a competing system, 20-year analysis. Assumptions: 1. 20-year analysis. 2. Salvage value at the end of 20 years, 20% of first cost. 3. First year energy savings of $30,000. 4. Maintenance costs or other operational costs, other than energy, were ignored. 5. Straight line depreciation over 20 years.

supplied. This savings was nearly offset by increased first costs elsewhere of about $75,000 for each 5,000-scfm (2.8 kg/s) increase in the OA supplied. The operating cost rose non-linearly with increasing OA flow. At 30,000 scfm (16.6 kg/s), the $3,170 first cost savings over the 25,000 scfm (13.8 kg/s) case was offset by the $5,110 increase in operating cost. The economics improved slightly at 35,000 scfm (19.4 kg/s) flow, since the annual operating cost increase is less than the reduction in first cost.

Because the first-cost savings were nearly or completely eliminated by the increase in operating cost, it is not recommended that the OA flow rate be increased as a means of reducing the first cost of the DOAS. However, a limited increase in the OA supplied to high cooling load perimeter spaces is recommended where necessary to limit the ceiling area required for the cooling panels.

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 the first cost.

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

$$BEFC = PWES - PWLTD + PWTDEP + PWSAL$$

Businesses	A Base Case	B $30,000 Annual Energy Savings
Profit Before Energy Expenses	$500,000	$500,000
Energy Expenses	($100,000)	($70,000)
Net Profit Before Taxes	$400,000	$430,000
Taxes, at 50% Rate	($200,000)	($215,000)
After Taxes Profit	$200,000	$215,000

Table 6: Hypothetical situation to illustrate the impact of lost tax deductions resulting from energy operating cost savings.

where

$BEFC$ = break-even first cost

$PWES$ = present worth of energy savings = $30,000 × p/a

$$p/a = \left(1/(i - in)\right) \times \left(1 - \left((1+in)/(1+i)\right)^n\right);\ \text{if } i \neq in$$

i = interest

in = inflation

n = years

$$p/a = n/(1+in);\ \text{if } i = in$$

$PWLTD$ = present worth of lost tax deduction from energy savings

$$PWLTD = \$30{,}000 \times \text{tax rate} \times p/a$$

$PWTDEP$ = present worth of tax savings by straight line depreciation of the equipment

$$PWTDEP = \text{tax rate} \times (BEFC/n) \times (p/a)$$

$PWSAL$ = present worth of the salvage value after taxes

$$PWSAL = (BEFC \times 0.2 \times p/f) \times (1 - \text{tax rate})$$

$$p/f = \left((1+in)^{n-1}\right)/(1+i)^n$$

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 where Business A is a reference and Business B realizes a $30,000 annual energy savings (reflected in the energy expense row). The energy savings caused the net profit before taxes to be higher for Business B by $30,000. The higher before taxes profit results in a higher income tax for Business B. As a result the after tax profit for Business B is only $15,000 higher than Business A. Had taxes not impacted the energy savings of Business B, the profit would have been $30,000 higher. The large present worth of the lost tax deduction from energy savings that are presented in *Table 5*, range from approximately $204,000 to $348,000.

Some observations that can be made from *Table 5* are:

1. If inflation is less than or equal to the annual interest rate, a non-profit organization can invest more than a taxed for-profit business and break even.
2. If inflation is greater the annual interest rate, a taxed for-profit business can invest more than a non-profit organization and break even.
3. When inflation is high, any investor can invest more up front than when it is lower and break-even.
4. When interest rates are low, any investor can invest more up front than when it is higher and break-even.

Finally, with a 20-year analysis and a first-year energy savings of $30,000, it would appear that from $330,000 to $1,230,000 extra could be invested in the mechanical system and break even.

Conclusions

The integrated DOAS/radiant cooling system has a lower first cost than a VAV system using TER by about $337,000, or $1.80/ft^2 ($19.50/m^2). Likewise the operating cost of the integrated DOAS/radiant cooling system is about 35% less than that of a VAV system using TER. For both of these reasons, the DOAS is economically superior.

The concept of increasing the DOAS supply air quantity in an effort to reduce the first cost of the radiant cooling panels was explored. It was found that the reduced cooling panel cost was nearly offset by an increase in the first cost of other mechanical equipment. And the energy consumed increase. It must be concluded that there is generally little or no benefit economically to increasing the DOAS supply airflow beyond the minimum required for ventilation.

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

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2. Mumma, S.A. 2001. “Ceiling panel cooling systems.” *ASHRAE Journal* 43(11):28–32

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New Planning Needed After Sept. 11

Those who fail to consider the possibility of extreme ambient events, such as building collapses, smog alerts and the like, open themselves to potential liability.

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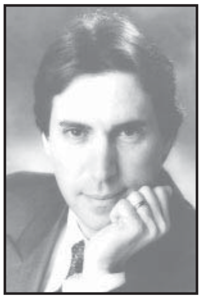
We think of pollution inside a structure as mostly caused by the materials and contents of the structure itself. But, on Sept. 11, we learned that the materials and contents inside one building can cause indoor pollution inside another building and health problems for their occupants. The destruction of the World Trade Center forces us to reconsider how we guard against indoor pollution, both from an engineering and a legal perspective.



Mark Diamond

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. Three days after the collapse, I received a call from my brother, who lives more than 150 blocks from Ground Zero, asking me if I thought the overwhelming smell was cause for concern. As the smell became even stronger, he, his wife, child and I fled Manhattan as if fleeing Rome in anticipation of invading hordes. That smell lingered, albeit to livable levels, for many weeks after the collapse.

Almost immediately after Sept. 11, word spread that asbes-