

HVAC: The Next

Outside-the-box thinking suggests the integration of dedicated

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Variable-air-volume systems came into favor primarily as a result of the energy concerns of the early 1970s. While they did wonders for that period, the 21st Century needs a new technology that overcomes the limitations of the old. That new technology may already be in place. As an HVAC strategy incorporating a dedicated outside-air source, radiant cooling and heat recovery promises to not only solve the

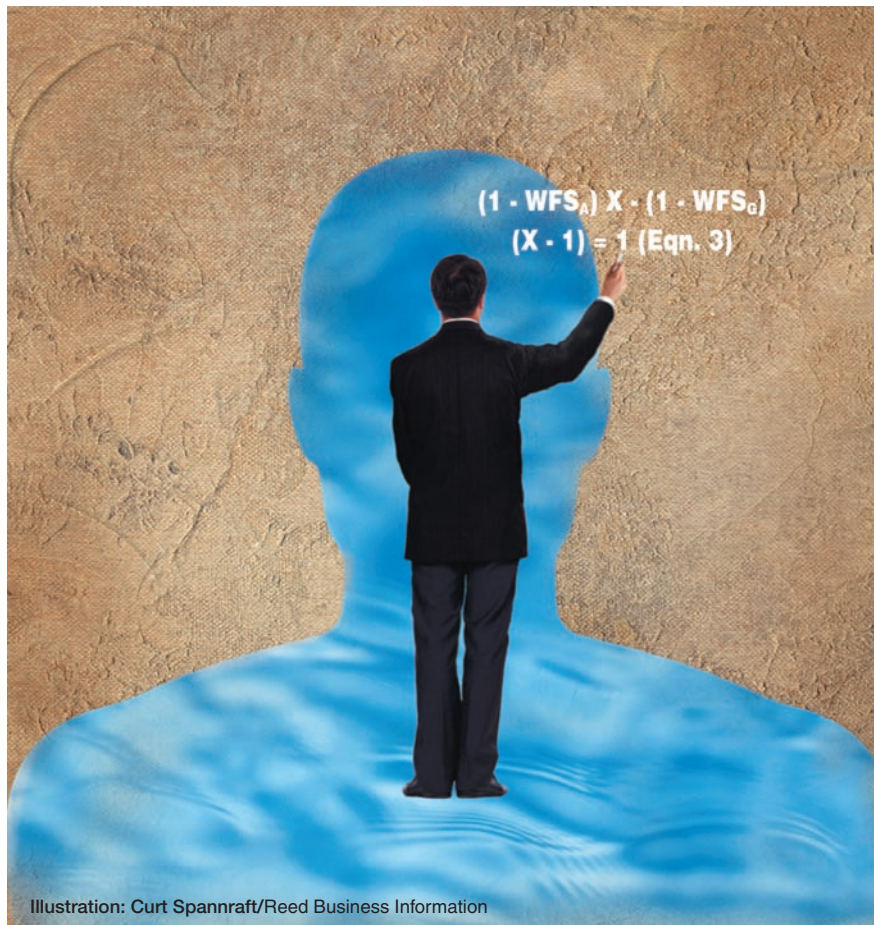
problems inherent in VAV, but may well revolutionize the industry.

What must be overcome

VAV clearly offers advantages over other all-air systems—terminal-reheat, dual-duct and multizone—including reduced fan energy consumption and greatly reduced bucking, which is simultaneous cooling and heating at part-load conditions. However, VAV systems have problems that the industry has been unable to solve over the past 30 years:

- ▶ **Poor air distribution.**
- ▶ **Poor humidity control.**
- ▶ **Poor acoustical qualities.**
- ▶ **Poor use of plenum and mechanical shaft space.** Large ducts and VAV boxes require deep plenums, increasing the first cost of the building envelope and everything else that moves vertically through the structure from columns and vertical circulation equipment to roof drains and ductwork.
- ▶ **Control problems.** This is particularly the case with tracking return fan systems.
- ▶ **Poor energy transport.** The density-specific heat characteristics of air make it one of the worst energy transport media imaginable.
- ▶ **Poor resistance to the threat of biological and chemical terrorism.** VAV systems blend huge quantities of recirculated air—often over 80%—with outside air (OA) at the air-handling unit.
- ▶ **Poor and unpredictable ventilation performance.**

Many have attempted to overcome these problems without sufficient success, but others in the industry are in denial about these problems. It is time to consider the next generation of HVAC.



Generation

outside-air, radiant ceilings and total energy recovery will key a new HVAC age

Hope for a new generation

Before delving into the particulars of the new system, let's first make a wish-list of what a next-generation HVAC system should do:

- ▶ Solve the inherent problems of VAV with special emphasis on the ventilation performance.
- ▶ Be available at equal or lower first cost.
- ▶ Demonstrate 30% to 40% lower operating cost than VAV.
- ▶ Exhibit superior humidity control, virtually eliminating microbial problems

In an industry where first cost rules, and the prevailing attitude is, 'If it's not broken, don't fix it,' it will take powerful persuasion to adopt anything new.

and associated sick-building syndrome.

- ▶ Demonstrate superior thermal and acoustical comfort.
- ▶ Be resistant to biological and chemical terrorism.
- ▶ Be capable of generating a higher number of LEED Green Building Rating Points than VAV systems.

Okay, now let's look at a next generation HVAC system on the books and in action at Penn State—the DOAS—and see how it meets our wish list criteria. The DOAS—dedicated outside air system—delivers 100% OA with ventilation air delivered to each conditioned space by a constant-volume OA unit utilizing total energy recovery (see Figure 1, p.40). By delivering ventilation air directly to each space, the OA flow rate is 20% to 70% less than that required by VAV systems, yet always meets the requirements of ASHRAE Standard 62.

Further, the OA unit removes all of the OA latent load and dries it sufficiently to remove the entire space latent load. This OA conditioning leads to a decoupling of the space sensible and latent loads, and to superior humidity control in the space—regardless of the sensible loads—thus essentially eliminating sick-building problems.

Finally, the OA unit is equipped with a total energy recovery device, specifically an enthalpy wheel, to cool and dehumidify OA in the summer. This reduces the OA load on the cooling coil by up to

80%. Furthermore, it significantly reduces the required size of the refrigeration plant for the building, often by more than 40%.

The enthalpy wheel also reduces the size of the winter heating and humidification plants and substantially reduces the energy consumed in many geographic locations.

By delegating all of the latent loads to the DOAS, or decoupling the space sensible and latent loads, the parallel system need only respond to the space sensible loads.

Of course, there is the question of parallel sensible cooling control. Fortunately, there are a host of options:

- ▶ Fan coil units operating with dry coils, which eliminate septic sources throughout the facility.
- ▶ VAV system operating with dry coils and only conditioning return air.

▶ Unit ventilators operating with dry coils and with the OA path sealed.

▶ Unitary air conditioning units operating with dry coils and with the OA path sealed.

▶ Ceiling radiant cooling panels.

HVAC system designers in the United States are familiar with the first four options. Radiant cooling, however, is something that is not commonly employed here—not yet, anyway. However, in combination with DOAS, it will eventually replace VAV (see “Radiant Ceiling Panels,” p. 40).

Back to meeting the goals of our wish list... The biological and chemical resistance of a DOAS/radiant system cannot be overlooked. Since the system does not use any recirculated air, biological or chemical agents—released accidentally or intentionally inside the building—are not transported to other parts of the building. Rather, they are diluted and exhausted from each individual space.

Moreover, since the quantity of OA that must be treated is generally 20% less than that of conventional VAV systems, extensive biological and chemical agent filtration/treatment of the entering OA is far more practical with the DOAS/radiant system in terms of both first and operating costs.

DOE affirms DOAS

Besides these facts, consider the finding of the government. In July 2002, the U.S. Dept. of Energy issued a report entitled, “Energy Consumption Characteristics of Commercial Building HVAC Systems: Volume III, Energy Savings Potential.” In that report, 55 of the most promising technologies were ranked, with the top 15 receiving detailed analyses

Radiant Ceiling Panels

There are a number of radiant ceiling systems available for heating and cooling applications. One type is comprised of panels that are an architectural finished product consisting of an aluminum absorption plate with copper tubes thermally and mechanically attached to the plate. The panels can be perforated to provide acoustical qualities. Panels are about the same weight as the acoustical tile they replace and are therefore responsive to load changes and have time constants of only minutes.

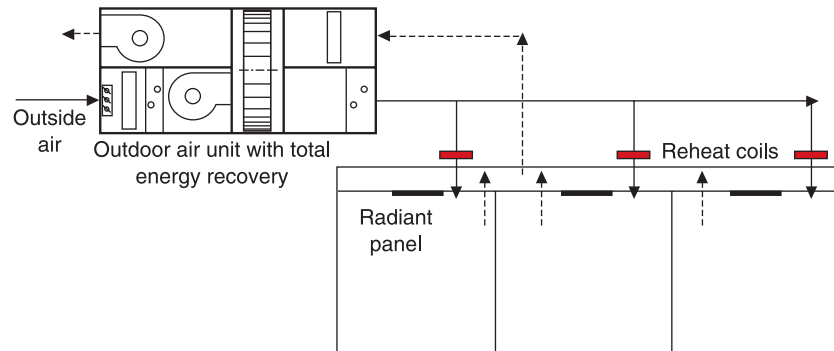
There are three drawbacks—condensation, lack of capacity and first cost. The former problems are addressable and cost can be offset with associated mechanical system reductions.

Although susceptible to *condensation*, the good news is that the phenomena is very slow forming. In fact, even a doubling of an occupancy will only form a film on the panels about the thickness of a human hair even after 14 hours. Further, a direct digital control system can be programmed to hold the panel fluid temperature above the space dew point temperature—about 55°F—to avoid condensation. Additionally, a passive fail-safe condensate sensor can be used, analogous to a cooling coil freeze stat, to isolate the panels from the cooling source.

Radiant panels lack *capacity* when held up to the 300-400 sq. ft. per ton of cooling rule of thumb typical of many facilities. In other words, about 40 BTU/hr-ft² of heat removal. Because a drop-in ceiling panel is capable of only about 30-35 BTU/hr-ft², it is assumed that the entire ceiling and part of the walls will require cooling panels. It must be noted, however, that the rule of thumb includes the outside air load and the space latent loads. To get a feel for what a typical VAV system sensible heat removal capacity is, consider this rule of thumb:

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Figure 1-DOAS With Parallel Radiant Cooling



The DOAS delivers 100% outside air with ventilation air delivered to each conditioned space by a constant-volume unit utilizing total energy recovery. By delivering ventilation air directly to each space, the outside air flow rate is 20% to 70% less than that required by VAV systems, yet always meets the requirements of ASHRAE Standard 62.

(see Table, p.41). The top energy-savings technology is radiant ceiling cooling, because water—an excellent heat transfer media—is used as the medium instead of air. The second energy saving technology is total energy recovery, and the third is DOAS. Imagine what the integration of these three technologies will produce. For one, their combined energy savings is 1.6 quads—almost as much as the other 12 technologies combined.

Another significant finding of the DOE report is presented in Figure 2, also on p. 41. On the basis of simple payback, both DOAS and radiant cooling have zero payback periods. This is certainly

raised. Installation began in the fall of 2001, with the mechanical system completed by January 2002. However, the web-based controls were not completed until early August 2002. Operating experience with the hot, humid summer conditions, as well as the cold winter conditions, are now in hand.

The project is located in a 40 ft. x 80 ft. architecture studio—the building was built in the early 1900s and the envelope had never been updated. It houses 40 students equipped with computers and task and overhead illumination.

The 1,200-cfm DOAS unit includes an enthalpy wheel. Air then enters the cooling and dehumidification coil, where it is

The combined energy savings of DOAS, total energy recovery and radiant cooling is 1.6 quads—almost as much as all the other promising DOE energy-saving technologies combined.

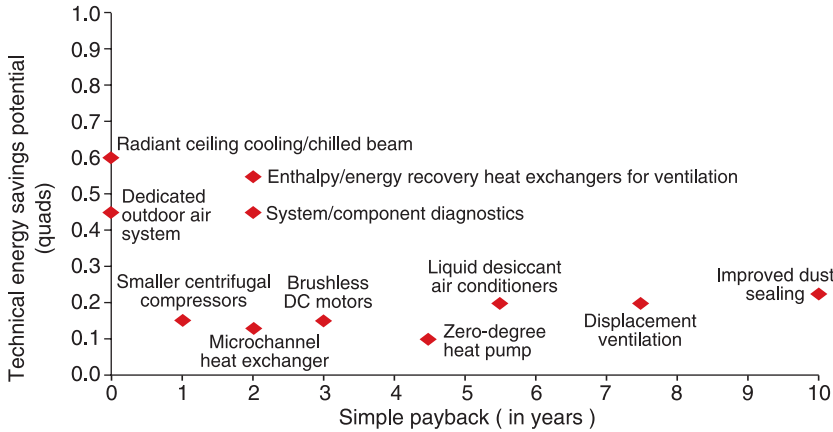
an attractive characteristic for the next-generation HVAC system.

Great, how do you do it?

About two years ago, planning began for the installation of the “proof of concept” project on the Penn State University campus in University Park, Pa. The building was selected, the design completed and financial and in-kind support

cooled to a dew-point temperature (DPT) of 52°F before entering the space through eight high-aspiration induction diffusers. Eight free-hanging radiant cooling panels, each 2 ft. x 40 ft., remove the balance of the space sensible heat. There is a passive fail-safe condensate sensor, and below a vertical run of uninsulated panel supply piping is where condensation would be concentrated by gravity and trigger the

Figure 2-DOE Simple Payback Estimates



On the basis of simple payback, both DOAS and radiant cooling have zero payback periods. This is certainly an attractive characteristic for the next generation HVAC system.

condensate switch. The system also includes the chiller, primary chilled-water pumps, a radiant-panel pump and a pair of three-way control valves to regulate both the temperature of the air leaving the cooling coil and the temperature of the water entering the radiant panels. The panel control valve is spring-loaded and hard wired through the condensate sensor. So, if the direct digital control system fails to maintain the panel water temperature above the space, resulting in DPT and condensation, the condensate sensor switch opens and the panels are immediately isolated from the source of cooling, stopping condensation immediately before any damage can occur.

OK, how does it perform?

Realtime performance data shows that when rather hostile OA of 85°F, 80% relative humidity (78 DPT and 148 grains/lb. humidity ratio) passed through the enthalpy wheel, it reduced the humidity ratio to 84 grains. Also, the enthalpy wheel reduced the OA load by 4.7 tons through energy recovery alone—over 35% of the total load at that time—without expenditure of chiller energy. At the cooling and dehumidification coil, another 4.5 tons of cooling was done, this time by the chiller. The OA leaving the high induction diffusers and entering the condi-

tioned space had a DPT of 52.4°F. The supply air was able to remove a combined sensible and latent load in the space of 3.3 tons as its enthalpy increased from 21.85 to 29.64 BTU/lbm. The radiant panels extracted the balance of the space sensible load, 4.1 tons, with water entering at 55°F and leaving at 60°F. At these design con-

ditions, the chiller provided 8.6 tons of cooling—the chiller is rated at 10 tons, but was downsized due to the 4.7-ton capacity of the enthalpy wheel—while supplying 49.5°F chiller water and receiving 60°F chilled water in return.

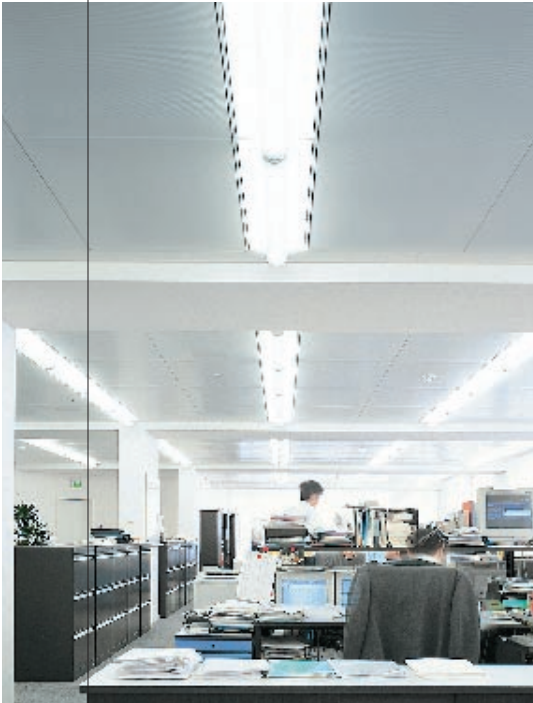
Operating observations

For a further sense of how the system has operated since startup, consider the following five points.

1. Operation of the panel control valve at startup. For the first month of operation, the system was operated manually for a complete understanding of how it would behave. When the system was finally started in the automatic control mode, the space and the chilled-water temperatures were both 85°F. Both control valves were 100% open at first. As the chilled-water temperature fell, it began to approach the space DPT, and the panel’s proportional integral derivative (PID) control valve loop modulated the control valve toward closed to prevent the panel entering water temperature from dropping below the space DPT. As the chilled-water temperature continued to drop and the DOAS supply air DPT dropped, the space DPT also dropped. As it

Table - U.S. Dept of Energy Top 15 Energy Saving Technologies

Technology	Status	Energy Savings in Quadrillion BTUs (quads)
Adaptive/fuzzy logic controls	new	0.23
Dedicated outdoor air systems (DOAS)	current	0.45
Displacement ventilation	current	0.20
Electronically-commutated	current	0.15
Permanent magnet motors		
Enthalpy/energy recovery heat exchangers for ventilation	current	0.55
Heat pumps for cold climates (zero-degree heat pump)	advanced	0.10
Improved duct sealing	current/new	0.23
Liquid desiccant air conditioners	advanced	0.2/0.06
Microenvironments/occupancy-based control	current	0.07
Microchannel heat exchanger	new	0.11
Novel cool storage	current	0.2/0.03
Radiant ceiling cooling/chilled beam	current	0.6
Smaller centrifugal compressors	advanced	0.15
System/component diagnostics	new	0.45
Variable refrigerant volume/flow	current	0.3



Although radiant panels have a high cost of purchase, in the end, overall cost results in a reduction of \$2 per sq. ft. of building floor area, considering associated mechanical system reductions.

did, the panel control valve PID loop allowed the panel water temperature to drop. This process continued until the space operative temperature set point was satisfied. Never was there any sign of condensation during automatic control operation, at start up or since.

The DOAS/radiant system has the potential to generate more than 80% of the points needed for LEED certification.

2. Balancing the DOAS airflows. At startup, the constant volume supply airflow was set at 1,200 cfm, and the return airflow was set at 1,150 cfm. The 50 cfm difference was enough to pressurize the space and cause a slight exiting flow around the doors and windows. Because this is a constant-volume system, the balance is not disturbed by load changes, as is the case with VAV systems.

3. Condensation experiences. In order to test the condensate sensor, the DOAS cooling coil was shut down and the chilled water in the panel loop reduced to 45°F. Condensate began to be visible almost immediately on the uninsulated water piping, but it took nearly an hour for enough condensate to cause a drop to fall. Within 10 minutes of the drop entering the vertical pipe onto the passive fail-safe condensate sensor, the switch opened and the spring-return panel control valve closed, isolating the panel from the cooling source. It should be noted that the pump is programmed to continue operating for 15 minutes after this event, thus quickly warming up the water through the system and terminating further condensation. Further, it should be noted that no water dripped from the horizontal water piping or the radiant panels in this test.

4. Concern about moisture migration thru the very porous space enclosure.

The space, with 1900s-era 12.34-ft. x 10-ft. single-glazed movable sashes, gave cause for moisture migration concerns. Remarkably, such migration has not been observed in the data, even when the outside DPT is 20°F higher than the interior DPT. The DOAS' slight positive pressure clearly has prevented moisture problems. Based upon this experience, it appears that a tight enclosure conforming to ASHRAE Standard 90 should prevent moisture migration problems.

5. Heating/energy recovery. The proof of concept project was intended to primarily provide summer cooling and dehumidification information, so no provision for heating was

provided. The existing space does have cast-iron wall-steam radiators, but their valves have been shut off, and the space operative temperature is maintained with an enthalpy wheel. Controls are in place to predict when the enthalpy wheel will frost, in which case the DOAS shuts down. Otherwise, the system is able to maintain 68°F operative temperature, with OA temperatures down to zero, since the constantly occupied space yields recoverable

Radiant Ceiling Panels

(Continued from page 40)

1 cfm/ft² supply airflow and 55°F supply-air temperature. If the space is maintained at 75°F, then the sensible capacity of the VAV system is 1.08*1 cfm/ft²*(75-55) or 22 BTU/hr-ft²—a value well below the 40 BTU/hr-ft². When the DOAS air is supplied to achieve load decoupling—i.e., a DBT equal to the required DPT—the load that is left on the panels is only about 15 BTU/hr-ft². So, capacity is not a problem, even with the ceiling only 50% filled with radiant cooling panels.

First cost is the final concern, but the DOAS/radiant approach results in reductions in the following systems compared to a typical VAV system:

- ▶ Chiller plant size
- ▶ Chilled water and condensing water pumps size
- ▶ Ductwork
- ▶ VAV box elimination
- ▶ AHU size (An 80%)
- ▶ Electrical service size
- ▶ Plenum depth, reducing the envelope area and vertical elements in the building
- ▶ Mechanical shafts, translating into less lost rentable space

As a result, the net effect is that the first cost of the mechanical system can be reduced by approximately \$2 per sq. ft. of building floor area.

heat from the lights and the computers.

Time for a change

Clearly, such results indicate it is time for the U.S. HVAC industry to move forward and adopt this next-generation system. Not only does it provide superior humidity control and thermal comfort without the noise, draft or chemical or biological agent distribution problems inherent in VAV systems, it can be employed with equal or lower first cost, yet still deliver 30% to 40% lower energy operating costs. Case closed. **lcse**