Photo 1 (left): Rental DOAS equipment at a Texas high school. Photo 2 (right) Temporary DOAS distribution ductwork.

DOAS & Humidity Control

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Using dedicated outdoor air systems (DOAS) within the HVAC market as the primary means of moisture removal has consistently gained a higher market share worldwide. Providing a comfortable and healthy indoor environment has been a difficult task for many commercial applications where ventilation rates are high, such as hospitals, schools, theaters, retail stores, hotels, restaurants, nursing homes, and office buildings.

Humidity control plays an important role in establishing and maintaining a comfortable indoor environment.[1] Using a DOAS in series or parallel with non-DOAS HVAC systems offers cost-effective humidity control when compared to dehumidification schemes using cooling coils and reheat. And, it provides the capability to meet the outside air ventilation rates as per ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*. In most applications, using DOAS in parallel with non-DOAS HVAC systems is the preferred method of application.

Fresh Air Ventilation

Introducing pretreated fresh air into a building can improve the IAQ and eliminate many problems associated with poor ventilation and lack of fresh air. Bayer notes that IAQ improves when using active humidity control and continuous ventilation in schools[2] to meet the requirements of Standard 62.1. In a study of 10 schools in Georgia, Bayer noted that of the five schools having HVAC systems without DOAS, none supplied outside air at the ASHRAE recommended 15 cfm (7.08 L/s) per person. The schools with desiccant DOAS dehumidification were delivering as much as three times more outside air, while maintaining equal or better control of the indoor relative humidity than the systems without DOAS. The average total volatile organic compound (TVOC) concentrations tended to be lower in schools with dehumidified air. The school showing the highest air exchange rate used a rotary desiccant system, and had the lowest carbon diox-

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ide, TVOC, airborne microbial concentrations, and the lowest average indoor relative humidity.[2]

In Phase II of the same project, Fischer and Bayer stated that increasing the air ventilation rate from 5 cfm to only 8 cfm (2.36 L/s to 3.78 L/s) per student challenged the ability of the non-dedicated outdoor air systems to maintain the space relative humidity below the ASHRAE and American Conference of Governmental Industrial Hygienists' recommended 60% level. Increasing the ventilation rate of the non-dedicated outdoor air systems to the recommended 15 cfm (7.08 L/s) per student allowed the space relative humidities to routinely exceed 70%. These data explained why all of the non-DOAS HVAC system schools were designed and/or operated with only 6 cfm (2.83 L/s) per student of outdoor air or less. The decreased ventilation rates were in direct response to the performance limitations of the non-DOAS cooling equipment and contributed to the poor IAQ within the schools. Schools served by the non-DOAS HVAC systems experienced absenteeism at a 9% greater rate than those served by the desiccant-type dedicated outdoor air systems.[3] Increased absentee rates can have significant negative economic impacts on a school or school system.

Packaged, non-DOAS HVAC equipment is not designed to handle the continuous supply of outdoor air necessary to comply with Standard 62.1. As a result, these schools are likely to experience IAQ problems.[4] Higher ventilation rates as specified by Standard 62.1 translate into greater cooling loads for non-DOAS equipment, specifically, greater latent loads during cooling seasons when indoor relative humidities must be controlled to inhibit growth of microorganisms that may result in health problems or damaged building materials.[5]

Non-DOAS HVAC systems cannot adequately dehumidify the air in warm and humid climates.[4,6,7] In a non-DOAS reheat system used for dehumidification, previously cooled air is heated and then introduced into the interior of a building. The air is first cooled to 55°F (13°C) or lower to remove the latent moisture load. This cold air is then reheated to satisfy the relative humidity and temperature requirements of the indoor space. Unless equipped with an energy recovery system, reheat systems used for dehumidification incur a quadruple penalty: (1) the first cost of the cooling generation plant, associated auxiliaries, and electrical service is increased by the amount of reheat and added cooling load; (2) the reheat coil first-cost premium includes increased electrical service and/or heating distribution piping; (3) the owner pays the annual operating cost for the extra sensible cooling of the air, and (4) then pays the annual operating cost of reheating the air.

To comprehend the advantages of enhanced dehumidification systems, it is vital that owners and HVAC system designers understand this quadruple penalty associated with the use of reheat systems. Reheat should not be the sole or first-in-control sequence means of dehumidification.[8] Buildings in the humid south should be pressurized to minimize infiltration of moist outside air and HVAC system design should incorporate dehumidification that maintains the space in the 45% to 55% relative humidity range during the entire cooling season.[8]

DOAS and the 45°F (7°C) Dew Point

A separate and dedicated outside air pretreatment ventilation system may be the only reliable method of meeting Standard 62.1 and is also the simplest method.[9] This separate dedicated outdoor air concept can be used to completely meet space latent loads, decoupling the space latent and sensible loads. The separation of the sensible and latent loads provides a mechanism for dehumidification when the building is in an unoccupied mode resulting in energy savings and low indoor vapor pressures to permit drying.

Designing the outside air system to deliver the required ventilation to each occupant requires a supply air dew-point temperature of about 45°F (7°C) to maintain a space dew-point temperature around 52°F (11°C). To determine the supply air conditions for a dedicated outdoor air system working in parallel with distributed sensible cooling equipment, one should select an air dew-point temperature low enough to maintain a summer space relative humidity no greater than 40%, or a supply air dew-point temperature around 44°F (7°C).[10] This results in the elimination of terminal reheat from the HVAC system and the ability to reduce the size of the cooling equipment due to the decrease in latent capacity required for non-dedicated outdoor air systems to dehumidify using subcooling and or reheat.[9] Excess cooling capacity can be subtracted from the rest of the system, resulting in savings that may offset the cost of the pretreatment equipment.[11,12] Reducing the latent cooling load burden of the refrigeration equipment results in a net increase in efficiency of the system, further offsetting initial purchase costs.[12] The proper use of DOAS can result in improved indoor air quality with little or no increase in compressor size or annual energy consumption.

Two ways to remove moisture from the air for air-conditioning applications are by cooling the air to condense water vapor or by passing air over or through a desiccant medium, which removes moisture from the air through differences in vapor pressures.[13] Some manufacturers use an energy-conserving combination of cooling and desiccation by first passing the outside air through cooling coils and using the waste heat generated by the cooling coil compressors to warm the air necessary for desiccant drying. One manufacturer of a combination cooling coil/desiccant system captures and sanitizes the condensed water for drinking.

Using the 45°F (7°C) dew-point design criteria via DOAS significantly reduces the potential for microbial growth within the non-DOAS HVAC equipment, as the dedicated outdoor air system lowers the dew point of the air. Both cooling- and desiccant-type DOAS remove water from the airstream. Cooling-based dehumidification chills air below its dew-point temperature, resulting in moisture condensation on the nearest surface.[13] Reheat may be necessary to increase the temperature for occupant comfort. Condensation within an HVAC system can result in microbial growth, equipment deterioration, and excess energy use and should be avoided in the design or retrofit stage. For these reasons, many engineers specify desiccant or combination cooling coil/desiccant DOAS for air-conditioning applications.

Since the mid- to late-1980s, desiccant-based cooling systems have found increased applications as humidity control devices as dedicated outside air pretreatment ventilation systems for non-industrial structures such as schools, homes, hospitals, and commercial buildings.[11,14] The use of active desiccants enhanced the quality of the indoor air by helping to maintain comfort criteria (temperature, humidity, and ventilation),[3,12,15] removing particulates and bioaerosols from the air,[15,16] and removing chemical pollutants from the air.[14,17] The application of desiccant dehumidifiers integrated with HVAC systems serves to precondition the outside ventilation air such that the latent load is removed. Some of the potential benefits of applying desiccant dehumidification to air-conditioning systems are humidity control, efficient latent load removal, and reduction in peak electric demands.[5]

Other savings associated with desiccant dehumidification–HVAC system hybridization include 1) providing an enhanced occupant comfort with lower energy use; 2) providing improved humidity control resulting in sensible versus latent cooling; 3) reducing equipment expenditures by allowing the downsizing of the evaporator coil, condensing units, distribution plenums and terminal boxes, air handlers, reduced ductwork size and cross-section, and space used for mechanical equipment for comparable design loads;[18] 4) allowing independent temperature and humidity controls; 5) allowing higher temperature setpoints due to increased evaporation off the skin of building occupants;[12] and 6) allowing for dehumidification and the complete shutdown of the sensible cooling equipment during unoccupied modes.

Desiccants have a natural affinity for removing moisture from air. As the desiccant removes water vapor from the air, the latent load is removed from air conditioning and the sensible load can be efficiently cooled mechanically to comfortable conditions. Solid desiccants take advantage of differences in vapor pressure to remove moisture from the air with energy required to heat regeneration air for removal of the adsorbed water from the desiccant medium. In many cases, the energy expenditures required for desorption can be offset by using waste heat from boilers, condensers, and other equipment. The honeycomb wheel-type desiccant is light, and its rotating mass is low compared to its high moisture removal capacity, resulting in an energy efficient dehumidification unit. The design is simple, reliable, and easy to maintain, and is the most widely installed of all desiccant dehumidifiers in ambient pressure applications like air conditioning.[13]

Investment Perception of DOAS

The main disadvantage of dedicated outdoor air systems is the perceived high first cost. The high initial cost is balanced by operational advantages discussed previously and application flexibility.[13] Regarding the appropriateness of desiccant drying systems for air-conditioning applications, the United States Department of Energy's National Renewable Energy Laboratory maintains:

> *Conventional vapor-compression cooling systems are not designed to handle temperature and humidity loads separately. Consequently, oversized compressors are installed to dehumidify the incoming air. And to meet humidity requirements, vapor-compression systems are often operated for long cycles and at low temperatures, which reduces their efficiency and requires reheating the dry, cold air to achieve some degree of comfort. Both consequences are costly. Desiccant systems, however, can supplement conventional air conditioners. By working together, they tackle the temperature and humidity loads separately and more efficiently. Heating, ventilating, and air-conditioning (HVAC) engineers can then reduce compressor size [when subcooling and/or reheat are eliminated from the system] and eliminate excess chiller capacity. Desiccant cooling systems are energy efficient and environmentally benign....Desiccant systems also displace chlorofluorocarbon-based cooling equipment, the emissions from which contribute to the depletion of the Earth's ozone layer....Desiccant dehumidification could reduce total residential electricity demand by as much as 25% in humid regions, providing a drier, more comfortable, and cleaner indoor environment with a lower energy bill. Desiccant systems allow more fresh air into buildings, thus improving indoor air quality without using more energy.*

A supply air dew-point temperature setting of 45°F (7°C) was used on a high school HVAC system retrofit project with active desiccant dehumidification,[19] which resulted in significant energy savings for the district. The authors provided criteria for the design and installation to address concerns associated with chronic high indoor humidity at a high school in a hot and humid southern valley of Texas.

The high school had a 1,000 ton (3517 kW) central plant with water-cooled centrifugal chillers and a primary/secondary chilled water distribution system. Non-DOAS air-handling units and fan-coil units were equipped with electric resistance heaters for heating and/or reheat. Controls were minimal direct digital control (DDC).

The criteria called for eight active desiccant-based air desiccant units with chilled water coils to cool the air to 55°F – 60°F (13°C – 16°C) prior to the airstream entering the desiccant wheel. Approximately 50% of the cooled air was bypassed around the desiccant wheel and mixed with the desiccant dried air to result in a neutral leaving air temperature (70°F – 75°F) (21°C – 24°C) at a dew point of 45°F (7°C).

Demand control ventilation control strategy with variable air volume (VAV) was incorporated in the design. Four chilled water outside air units with electric reheat were replaced with four of the desiccant units to provide the proper amount of conditioned outside air for the existing classroom fan-coil units. The other four desiccant units provided conditioned outside air to the RA/OA mixing box of 12 existing air-handling units serving other areas of the building. Variable frequency drives were added to eight VAV handling units. The existing DDC system was replaced with a system sufficient to manage control and operation of the central plant and DOAS–HVAC system.

The HVAC system retrofit took place while the school continued to hold classes for the approximately 2,500 students. This was accomplished by installing multiple rental chillers, pre-cooling coils, active desiccant drying equipment, and post-cooling coils for temporary DOAS while the permanent systems were installed (see *Photos 1* and *2*).

The purchase, retrofit, and installation cost of the desiccant and air-conditioning systems was $2.1 million (~$17.50/cfm of OA [$37.08 per L/s]). Building utility (electricity, gas, and water) operating consumption (costs) for the calendar year prior to the retrofit was compared to the calendar year following the retrofit. As a result of the desiccant installation, the school reduced its building operating costs from $117.25/operating hour to $53.49/operating hour while increasing ventilation rates to meet Standard 62.1. The payback period for the initial $2.1 million investment was 3.75 years. The present worth of the investment was $5.8 million dollars based on an interest rate of 4% and a service life of 20 years without an adjustment for increasing energy costs. This retrofit project shows the application of desiccant technology as an IAQ control strategy in humid climates can provide significant economic benefits to building owners and the community.

As described previously the payback period associated with providing a desirable indoor environmental quality is short.[4] Fischer indicated that the many benefits listed would be recognized year after year, whereas the costs associated with providing the desirable indoor environmental quality are a one-time expense with minimal maintenance costs. The expected benefits—which included reductions in absenteeism and health-care costs; positive impacts on productivity and alertness; decreased incidences of drowsiness, allergies, and illness; avoidance of property damage and remediation; and reduced maintenance costs—quickly exceeded any initial expense associated with facilitating an improved indoor environment.[2]

Kumar and Fisk proposed that costs associated with providing additional ventilation may be more than offset by the savings that result from reduced employee sick leave, and that increasing ventilation rates above the minimum rates specified in Standard 62.1, can yield substantial benefits, including the reductions of the incidence of allergy and asthma in building occupants.[20]

Time for Acceptance

A widespread perception exists that HVAC systems using DOAS have higher first costs than non-dedicated outdoor air systems. The authors routinely encounter engineers who are strongly opposed to considering DOAS when designing mechanical systems for buildings in humid climates. These poor perceptions of DOAS are the result of the HVAC system industry's unfamiliarity with DOAS, in general, and the relatively recent application of active dehumidification to separate the sensible and latent loads. When viewed as an investment, DOAS can provide significant benefits with substantial savings. The use of DOAS, specifically desiccation, falls outside of conventional HVAC system design,[21] but the benefits of using these systems dictate the need for change and transformation to a new paradigm within the HVAC system industry. From 1997 through 2001, 6,700 new desiccant installations for IAQ- and ventilation-specific applications occurred nationwide without significant awareness, education, and training regarding desiccant–HVAC hybridization within the HVAC system industry.[1]

Strong proponents of using DOAS in HVAC applications are the U.S. Department of Energy, the Air-Conditioning, Heating, and Refrigeration Institute, and the authors. Although active desiccation–HVAC hybridization remains a highly controversial subject within the industry,[1] the use of cooling coils as a DOAS is somewhat accepted. It is unlikely that the increased use of dedicated outdoor air systems for IAQ- and ventilation-related applications is the result of chance, but appears to be due to the insights of engineers and designers who realize the increased value of DOAS for HVAC system applications. The use of DOAS for air-conditioning applications may become the norm, as energy costs rise and their increased use provides evidence of increasing acceptance and benefits of use within the industry.

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