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NIST Interim Report 7244: July 2005
By S. J. Emmerich and T. McDowell:
Initial Evaluation of Displacement Ventilation (DV) and Dedicated Outdoor Air Systems (DOAS) in Buildings.
Report funded by the U.S. Environmental Protection Agency, with the objective of charting future research work.

Overall Comments (by Mumma):

1. The authors demonstrate many of the common misconceptions held by the industry relative to both DOAS and DV. Specifically:
    a. <u>DOAS is different than DV</u>. In fact it takes a DOAS to supply a true DV system (a system providing only OA at floor level and warm enough to prevent cold feet). But a DOAS system works fine with overhead high induction diffusers, and in some instances is the preferred option because the air can be supplied at very low temperatures without introducing discomfort.
    b. <u>DOAS does not involve conventional mixing ventilation approaches</u>. Many parallel sensible cooling technologies are available for use with DOAS; one of them is a conventional VAV system.
    As the authors note on page 14, an ASHRAE article by Khattar and Brandemuehl describe a project that uses what they call DOAS with a VAV system. In their case, the DOAS preconditions the OA so it contributes nothing to the latent load of the space, and could be made dry enough to also take all of the space latent loads. The air from the DOAS is then introduced in the VAV AHU just down stream of the cooling coil. In this case the DOAS is involved with conventional mixing ventilation. This solves some of the inherent problems of VAV, but not many. Consequently Mumma is not in favor of this application of DOAS since we can do much better.

2. The authors introduce another misconception and conclusion, i.e. that DOAS does not assure good space humidity control. This comes from confusion about what DOAS is—an understandable situation given how the concept of DOAS is used in the HVAC industry. It also comes from a misunderstanding about how the parallel equipment must operate. In this project, the authors allowed the HP evaporator to operate at apparatus dew point temperatures (DPT) way below the desired room DPT of approximately 55F. As a result they noted from their simulations latent cooling at the HP's resulting in spaces with DPT's unnecessarily low.

3. The three faces of DOAS, as used in the HVAC industry are as follows.
    a. One DOAS face, as advanced by Khattar et.al. is that DOAS is simply a <u>dual path through the air-handling unit</u>, with both the recirculated air and the OA distributed in a single VAV duct system. The biggest problem with this approach is the difficulty assuring proper ventilation to all spaces. Another problem with this approach is the need to over ventilate to meet the ventilation requirements of the critical space, thus conditioning considerably more OA than would be necessary if the correct OA were supplied to each space.
    b. A second DOAS face, presented by the authors of this report, provides OA directly to each space with no preconditioning, or limited preconditioning (an Enthalpy Wheel (EW) is utilized).
    With no or incomplete preconditioning, significant latent load is delivered to the

plenums containing the terminal heat pump units. It is certain that there will be significant hours when the HP's will not be up to the task of treating the mixed air latent loads. And in fact humidity control is compromised. Significantly, a DOAS without total heat recovery (EW) is a violation of ASHRAE Std. 90.1, except for very small systems.

   c. The third DOAS face, and the one always advanced by Mumma, both dehumidifies the OA before introducing it to the space, and delivers that OA directly to the spaces. If the terminal equipment is a fan coil unit or a heat pump, as discussed in this report, the DOAS air should be introduced into the supply ductwork down stream of the coils. It is only this third DOAS face that will assure good space humidity control, ventilation, and dry condensate pans. And only then if the terminal equipment cooling coils are operating at or above the desired space DPT.

4. The authors' concept of "full DOAS" is very confining. Mumma considers only the third face of DOAS to be full DOAS, i.e. it accomplishes both dehumidification to decouple the space sensible and latent loads as well as delivering the proper OA to each space. Full DOAS should not be limited to this NIST report definition as prescribed on page 21.

5. The base, partial and full DOAS cases discussed by the authors fail to meet the economizer requirements of ASHRAE Std. 90.1. It will be discussed later in this evaluation

6. As a general rule, it is wise with DOAS systems to have the ability to achieve humidity control during unoccupied periods. Generally this requires that return air can pass over the cooling coil when the OA dampers are closed. The authors overlooked this issue.

Specific comments (by Mumma):

7. On page *iv* of the report the authors could only report finding one DOAS project—in a Florida School. Actually there are so many DOAS projects in this country now that it has become commonplace.

8. On page 13, the authors admit that they may have missed some reports on DOAS. Mumma concurs, based upon the fact that on page 14 of their report they reference a web site that over 3 years ago became only a pointer to the latest information on DOAS: http://doas-radiant.psu.edu

9. It is interesting that the authors chose to analyze 4 different systems, all of which represent one of the faces of DOAS. The report fails to compare any of these DOAS approaches with the office building standard for the industry: VAV. This is a an unfortunate decision since VAV systems almost universally do not use EW's, (since VAV systems are not required by ASHRAE Std. 90.1 to use energy recovery) capable of cutting the size of the chiller (and demand charge) by about 40% in most cases. VAV systems also are required, due to ASHRAE Std. 62.1, to condition from 20-70% more OA than that of a properly designed full DOAS delivering the dehumidified ventilation air to each individual space. These two differences between DOAS and VAV, along with vastly different fan energy use, make the DOAS decisively more energy efficient than VAV systems.

10. The authors recognized that one of the short comings of DOAS is its inability to utilize 100% air side economizer: a topic addressed at the following web link: http://doas-radiant.psu.edu/IAQ_Econ_Pt1_Fall_05.pdf
In an effort to explore the benefit of such an economizer cycle with DOAS (pg 20 of the report), they added an economizer capability to the base case where untreated OA was supplied to each water source heat pump terminal unit.

11. On pages 20 and 21 the authors discuss the operation and control of what they call a simple DOAS, i.e. an EW was added to recover energy from the exhaust air stream to partially precondition the OA. On page 21 the EW control is described as follows: *it operates anytime OA is required*. Operating this way essentially eliminates the ability to realize any air side economy, since the recovered exhaust air heat elevates the supply air temperature to levels much higher than outside temperatures. This causes unnecessary energy use and wear on the cooling plant. In addition, whenever the OA enthalpy is below the return air enthalpy, operating the EW increases the cooling energy use.

12. On page 21, full DOAS is defined by Figure 5 as consisting of the fans, EW, CC and sensible wheel (SW). This arrangement has been addressed in the literature as DOAS, but many other arrangements are capable of full DOAS, i.e. decoupling the space sensible and latent loads and delivering the ventilation directly to each space.
    a. For applications such as offices and others with low occupancy density, it is very difficult to overcool with just ventilation air—even when supplied as low as 45F. And depending on the selection of parallel system and schedules, any terminal reheat (yes it is permitted by Std. 90.1) would be minimal (by comparison, Mumma has shown that DOAS would use less than that required of a VAV system meeting the ventilation requirements of the spaces). And with the WSHP's studied in this report, the reheat would be very inexpensive. **<u>The point is</u>**: with low occupancy density spaces, the cost and complexity of the sensible wheel is completely unjustified.
    b. High occupancy density spaces, like conference rooms or classrooms, often require a ventilation flow rate approaching that required to meet the space sensible loads. Under these situations, it is a good idea to use the SW, but with proper controls so at design low DOAS supply air temperature (SAT) is used (see papers on the doas-radiant web page). Unnecessarily elevating the DOAS SAT at design requires the parallel sensible equipment to take more of the load—increasing, sometimes significantly, the first cost of that equipment.

13. The authors modeled the full DOAS with a natural gas fired furnace preheat coil to prevent EW frosting. Not a bad idea for a small office, particularly since it avoids a heating coil freeze-up. There are other controls that can be used to prevent damage to the EW, should frosting be encountered. It has also been a common practice to place the preheat coil ahead of the EW in the exhaust air stream, thus greatly minimizing any potential for freezing.

14. The SW simulation description is so brief that its accuracy cannot be checked! When a SW is used as illustrated in figure 5, it reduces the sensible cooling capability of the DOAS supply air. In the process, it sensibly cools the return air, lowering the temperature of the air entering the exhaust airside of the EW. The impact is that the load on the DOAS cooling coil is reduced. The authors have been asked to verify that this actually happens in the simulation, but have yet to respond. As shown in the Shank-Mumma paper on the DOAS-radiant web site, the overall impact of adding the SW is to reduce the CC load while increasing the chiller load (since the EW can't recover as much energy as is lost in the SW).

15. The results presented on page 25 compare apples and oranges. Both Jeong et al and Khattar et al compared DOAS with VAV systems, while these authors only compare variations within the family of DOAS—so their results cannot be compared with those of Jeong or Khattar. And the conclusion that the full DOAS had only slightly higher energy savings than the basic DOAS completely missed the fact that only the full DOAS offers humidity control. The other DOAS approaches analyzed would lead to serious humidity problems in many cases and geographic locations.

16. In the Summary section 3.3, page 26, the authors express the misconception that decoupling the space sensible and latent loads is so radiant cooling can be used. If the DOAS can handle all of the OA and all of the space latent loads, then the WSHP (or fan coils) can operate with dry coils, thus reducing septic amplifiers all over the building—a biological hazard just waiting to happen. The authors further state that humidity control has been cited, but has yet to be proven. A statement clearly made to attract more money for research. Mumma has documented in the literature the superiority of the DOAS for latent load control. More on load decoupling in item 18.

17. In the section 3.3 the authors correctly express concern about building pressurization. In a small two-story office building pressurization is not difficult to achieve. The industry has some very accurate bleed sensors that can be used in the return fan control, holding the building at the desired pressure condition. Pressurization is much more of a challenge with tall buildings, where some vertical compartmentalization may be required to minimize leakage.

18. In the 3.3 Summary on page 26, the authors say "*The more complex DOAS system modeling still*

showed latent cooling being provided by the WSHPs in the zones. While this does not mean that the radiant system would not provide adequate comfort to the occupants without surface condensation, further study of this issue is needed." As noted elsewhere in this evaluation, condensation will occur if the cooling surfaces are below the space DPT, as was the case for the authors' simulations. Radiant cooling surfaces must always be above the space DPT, and generally are at about 60F. The DOAS web site has many papers dealing with radiant cooling condensation control. A common misconception in the industry is that all cooling equipment operates with 45F-chilled water or surfaces. Clearly radiant cooling cannot be allowed to fit that false paradigm.

Note: Mumma did not check the design conditions for the authors' simulations. However it is worth discussing how the DOAS supply air DPT (humidity ratio) must be selected. It is based upon the application of the following equation:

$Q_{latent}=0.68*scfm*(W_{room} - W_{DOAS\text{-}supply})$.

If a space has 25 people each generating 205 Btu/hr of latent load, and an additional latent load from other sources equals 400 Btu/hr, then the total latent load is 5,525 Btu/hr. If that room is supplied with 500 scfm of OA, the resulting increase in humidity ratio is 16.25 grains/lbm_{DA}.

If it is desirable to maintain a space condition of 74F, 50% RH (W_{room}, and DPT_{room} are 62.76 grains/lbm_{DA} and 54.2F respectively), then the supply air condition, must have a humidity ratio of 62.76-16.25, or 46.51 grains/lbm_{DA}. This corresponds to a DPT of 46.3F. That means radiant panels could operate at about 55F and experience no condensation. It also means that if, as simulated in this NIST report, the WSHP cooling coil is operating below 54F they would be doing some latent cooling—as observed. Using WSHP's with dry coils 100% of the time requires careful simulation and selection of the equipment.

This example can be expanded to illustrate what the resulting space condition would be if, for example, the engineer wished to supply the OA with a 52F DPT. This corresponds to a humidity ratio of 57.81 grains/lbm_{DA}. With the same load and OA flow rate, the resulting room conditions would be 74F and 58.85% RH (74.06 grains/lbm_{DA}, DPT=58.71F).

Finally, in order to meet the space latent load the supply air quantity is a design variable, in addition to the desired space conditions and the supply conditions. Since Green building points can be obtained by increasing the OA flow by 30% over those required by ASHRAE Std. 62.1, that should be kept in mind. While the fan energy would increase, the chiller load would be essentially unchanged because of the EW. And the SAT could be elevated, possibly reducing the first cost of the Chiller and associated operating costs.

Mumma ***<u>ALWAYS</u>*** recommends selecting the DOAS unit near the lower end of its rated flow rates, so reserve capacity will be available in the future should the latent loads experienced exceed those expected! This is where the safety factor needs to be applied. For example, if the DOAS needed to supply 4,500 scfm of OA, one equipment selection might be applicable in the range from 3,000 scfm to 4,500 cfm. The next size equipment choice might range from 4,500 to 8,000 cfm. The EW effectiveness for the smaller selection might be 75%. While the larger size selection, which affords a latent capacity safety factor, also has lower face velocities and pressure drop resulting in higher EW heat recovery effectiveness of 85%. Careful economic analysis generally justifies the larger selection.

19. The authors are to be commended for their desire to provide the industry with more information concerning DOAS.

<u>The intent of this review is to educate rather than criticize. Please take it in that spirit.</u>