ASHRAE'S DOAS WEBCAST:

A DEEPER EXAMINATION OF THE ROLE OF HEAT PIPES

Tom Brooke MBA, PE, CEM

May 25, 2012

INTRODUCTION

On April 19, 2012, ASHRAE conducted a webcast to publicize the concept of Dedicated Outside Air Systems (DOAS)[1], an alternative, and many would say preferred, basic system to Variable Air Volume (VAV) systems. ASHRAE and the speakers did an excellent job presenting the complete systems' pros, cons and its more controversial aspects. The webcast explicitly acknowledged heat pipes as a valuable contribution to DOAS, but the subject of DOAS is so broad and so many other more fundamental issues needed to be discussed that its coverage of heat pipes wrapped around the cooling coil was necessarily very brief. This paper is meant to continue the heat pipe discussion where the webcast ended and provide a deeper and more comprehensive understanding of the value of heat pipes wrapped around the cooling coil.

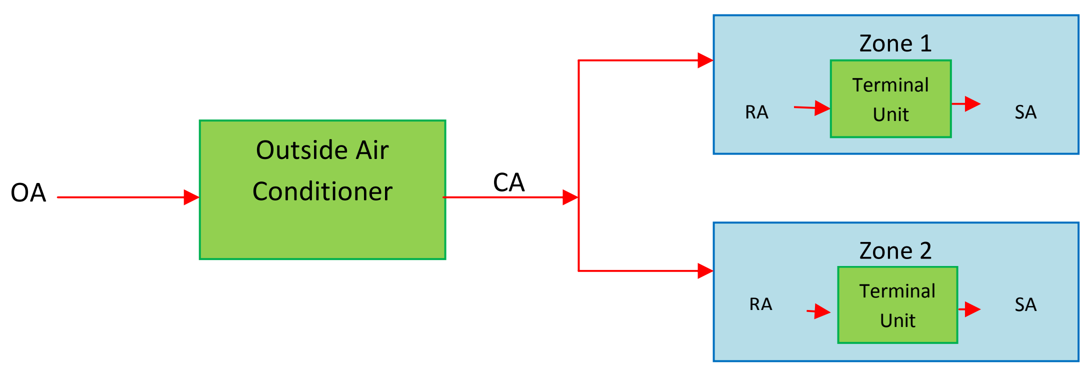

FIGURE 1 – Dedicated Outside Air System (DOAS)

DOAS was initially developed to insure that the correct amount of ventilating fresh outside air (OA) would be supplied as conditioned air (CA) to all the zones supplied by a system under all operating conditions (as defined by ANSI/ASHRAE 62.1) by using a separate ductwork system. Terminal units with their own return air (RA) and supply air (SA) are located within each zone to handle primarily the sensible load. As the DOAS concept has evolved over the last decade, other system aspects also became generally, although not yet totally, accepted as part of the concept.

[1] A DVD with the webcast is available from ASHRAE at: http://www.techstreet.com/cgi-bin/detail?product_id=1830066

1. The equipment conditioning the OA is charged with removing not just the moisture from the OA, but also the moisture load from both external and internal sources for all the zones.
2. The byproduct of the first item is that the zone terminal equipment does not remove any condensate from the air, and thus the terminal equipment only sensibly cools.
3. ANSI/ASHRAE Standard 90.1 now mandates energy recovery over most of North America for most size systems, and the natural position for energy recovery is in the equipment conditioning the OA.

In 1986, Heat Pipe Technology invented the idea of using a heat pipe (one type of Air-to-Air Heat Exchanger [AAHX]), wrapped around a cooling coil to specifically reduce the equipment's Sensible Heat Ratio (SHR) and enhance dehumidification[2]. Since both the heat pipe concept and DOAS improved moisture removal, it should

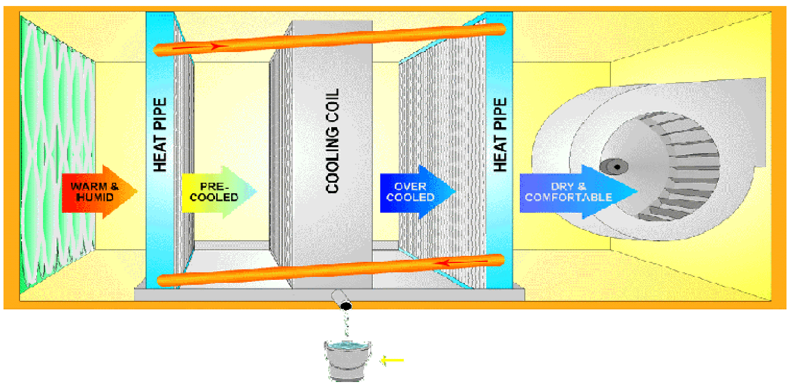

FIGURE 2 – Heat Pipes for Dehumidification

be expected that their paths would cross. In that quarter century, HPT has designed and installed thousands of heat pipes wrapped around the cooling coil for DOAS applications with DX, chilled water and brine coils for both new and retrofit installations.

While heat pipes are also often used for heat recovery between the Exhaust Air (EA) and Outside Air (OA), this paper only addresses the dehumidification application. The reader is referred to other papers, engineering data, case studies and catalogs available at heatpipe.com for the solutions that advanced heat pipes bring to EA heat recovery[3].

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[2] U.S. Patent Number 4,607,498

[3] Archived Webinar 11/17/2011 by Dr. Michael West, "Optimizing Energy Recovery with Heat Pipe Systems".
Archived Webinar 4/11/2011 by Mr. Tom Brooke, "Today's New Paradigm for Heat Recovery"
White Paper January 2012 by Mr. Tom Brooke, "Indirect Evaporative Cooling with Heat Pipes"
White Paper 4/11/2011 by Mr. Tom Brooke, "Today's Paradigm for Air-To-Air Heat Recovery"

SHOULD THE CONDITIONED AIR (CA) FROM THE DOAS UNIT BE COLD OR NEUTRAL?

The webcast posed that question and answered that it should be cold, which seemingly disallows the installation of heat pipes wrapped around the cooling coil. But then the webcast acknowledged that there are at least four DOAS applications that then need reheat, which is where the heat pipe should be used. This paper's position is that the CA dry bulb doesn't have to be limited to only being at the extremes of cold (around 55 ºFDB for standard comfort conditioning applications) or neutral (around 72 ºFDB). Rather, for superior energy savings while maintaining IAQ for <u>all</u> applications, the CA dry bulb should float between those two extremes. Possibly, while aware of the lack of modulating capability of most types of wrap around AAHX, the webcast presenters are not aware that wrap around heat pipes certainly do have that modulating capability.

The CA dew point must of course be low enough to satisfy the ventilating air's and zone total's latent load; on that we all agree, and that provides our starting point. Conceptually then, it's simple enough to understand that the CA dry bulb should equally be low enough to satisfy the ventilating load's and some amount of the zone total's sensible load. Specifically, as much as possible of the total sensible load should be handled by the unit conditioning the OA, BUT not so much that there is a need for any reheat in <u>any</u> zone. Sure, it's likely that the CA will need to be cold at design conditions, but what about at the other 99% of the time? That 99% is when the CA dry bulb should be allowed to rise. Why? Here's where the genius of the wrap around heat pipes comes in … because the reheat furnished by the heat pipes in the OA conditioning equipment is exactly the same heat that's taken from the air stream just upstream of the cooling coil. Heat is just moved through the heat pipes from the pre-cool side to the reheat side, and no outside energy is needed for either that pre-cooling or that reheating! So the more reheat there is, the more is saved in pre-cooling, and the more total energy is saved. From another perspective, Figure 3 shows that the lower the CA dew point, the more total cooling and reheating energy is saved. It should be clear then that supplying reheat at the OA conditioning unit is always preferred because then there are cooling savings too. The high limit for the amount of reheat is the point where <u>any</u> terminal unit has to provide any cooling to maintain any zone dry bulb set point. Now let's back up and examine several other building codes, cooling load, and equipment practicalities that contribute to this considered decision.

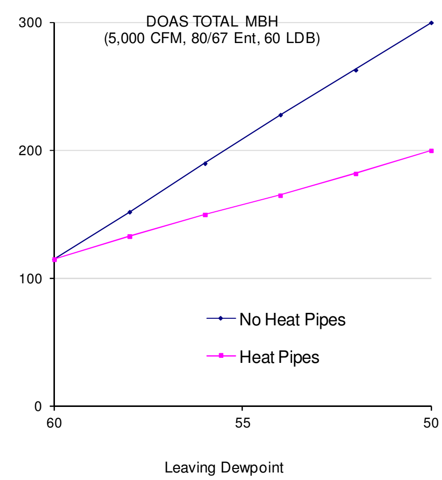

FIGURE 3

First, paragraph 5.9 of ASHRAE Standard 62.1-2010, "Ventilation for Acceptable Indoor Air Quality" specifically addresses relative humidity[4]. While practicalities are acknowledged, the language is strong and directs our

[4] The exact and complete wording of Paragraph 5.9 of ANSI/ASHRAE Standard 62.1-2010 follows: "5.9 **Dehumidification Systems**. Mechanical air-conditioning systems with dehumidification capability shall be designed to comply with the following. 5.9.1 **Relative Humidity**. Occupied space relative humidity shall be limited to 65% or less when system

designs to be more pro-active in designing for humidity control by having us consider situations with a Sensible Heat Ratio (SHR) that's far below the design SHR (duplicating real world part load conditions). For the impact of this seemingly innocuous paragraph, consider a recent DOAS focused article in the ASHRAE Journal[5]. It listed the sensible and latent loads in a typical classroom, and determined a .72 SHR at design conditions.

	Design DB/ MCWB	Design DB/ MCWB	Design DP/ MCDB	Design DP/ MCDB
LOADS	w/ Solar	w/o Solar	w/ Solar	w/o Solar
Sensible BTUH	28,369	18,469	22,908	13,008
Latent BTUH	11,278	11,278	19,228	19,228
Total BTUH	39,647	29,747	42,136	32,236
SHR	.72	.62	.54	.40

FIGURE 4

However, when the conditions spelled out in paragraph 5.9 of Standard 62.1 are applied (FIGURE 4), the SHR is reduced to .40. Psychrometrically, a SHR below about a .55 usually needs some form of reheat. Therefore, to maintain IAQ in nearly all comfort conditioning applications, the reality is that the SHR of the load at part load conditions forces the equipment's SHR to match it, thereby requiring reheat of some form.

Second, while any standard terminal cooling equipment can be used for DOAS, at least two (radiant cooling panels and chilled beams) are made to order for this application because they can only do sensible cooling. But even more so, one of the precepts of DOAS that's gaining agreement is that even units like air handling units (AHU) and fan coil units (FCU) that can pull latent from the air and have drain pans should be run dry to minimize potential sources of microbial growth, minimize maintenance and use less energy. In any case however, the dew point of the CA from the DOAS unit is increasingly seen to be below the dew point of the air in the zone so the terminal unit can be run dry.

ASHRAE Standard 55 - 2010 defines the "Thermal Environmental Conditions for Human Occupancy" and 78 ºF is near the middle of that dry bulb range for summer. The commonly used 50% indoor relative humidity then defines a 57.8 ºF zone dew point. Allowing for a conservative three degrees (7.7 gr/lb) to counteract the interior latent load plus three degrees of safety brings us to a practically needed 51.8 ºF dew point of the CA for a mundane (albeit at 50% RH) comfort conditioning application.

Assuming a draw thru design with 2 ºF motor heat, now the question is: "Is 53.8 ºF CA dry bulb temperature needed for zone cooling?" Sure, at design conditions, but not 99% of the time! As long as the CA's dew point meets the zones' and ventilating air's latent loads, the dry bulb can be higher. They are NOT linked together, and

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performance is analyzed with outdoor air at the dehumidification design condition (that is, design dew point and mean coincident dry bulb temperatures) and with the space interior loads (both sensible and latent) at cooling design values and space solar loads at zero. ***Note:*** System configuration and/or climatic conditions may adequately limit space relative humidity at these conditions without additional humidity-control devices. The specified conditions challenge the system dehumidification performance with high outdoor latent load and low space sensible heat ration."

[5] Jeong, Jae-Weon and Mumma, Stan. 2006. "Designing a Dedicated Outdoor Air System with Ceiling Radiant Cooling Panels." *ASHRAE Journal.* 53(10):56-66.

as was discussed earlier, that distinction of the sensible heat difference provides an important energy saving ability, as we'll see!

Third, energy analysts argue that reheat requires energy and it doesn't make sense to use energy for reheat at the DOAS unit, only to have to re-cool it back down at the terminal unit. Well, can't argue with that! However, now consider a sensible AAHX like a heat pipe wrapped around the cooling coil. This type of AAHX uses heat from the upstream side of the cooling coil for free reheat, and moreover, that saves exactly that much cooling energy. Therefore, the more reheat that's accomplished, the more free cooling is gained. This leads to the inescapable conclusion that to save the maximum overall system cooling energy, control the reheat amount so that it is the maximum while still allowing all zones' sensible cooling requirements to be met without reheat. Conversely, if sensible cooling is occurring at all zones' terminal unit, then energy is being wasted.

Fourth, paragraph 6.5.2.3 of ASHRAE Standard 90.1-2010 prohibits reheat except in five situations and none of those situations is a standard comfort conditioning application where DOAS is often applied. However, one of those five situations is when "at least 75% of the energy for reheating of for providing warm air in mixing systems is provided from a *site-recovered* (including condenser heat) *or site-solar energy* source." One hundred per cent of the reheat in a wrap around heat pipe is site-recovered (even better, it's also free cooling!). Using wrap around heat pipes frees the designer from coming up with artful logic why their reheat should be allowed in routine comfort conditioning applications.

Fifth, since most commonly available and used building simulation programs don't model sensible AAHX wrapped around a cooling coil, a spreadsheet based program that just models the OA conditioning unit and the terminal units was developed to do that. To eliminate bias, the previously cited article by Jeong and Mumma described the DOAS system that was used as the model for the program, the program was validated, and Seminar 23 at the ASHRAE Winter Proceedings in 2010 presented the results. The APPENDIX provides the specific details.

St. Louis was chosen as the base case, as it's roughly the center of the US. FIGURE 5 shows the key result of the study, which is that as the heat pipe rows increase, the savings also increase, albeit at a diminishing rate. For the combined cooling and reheating (not including winter heating), there is a

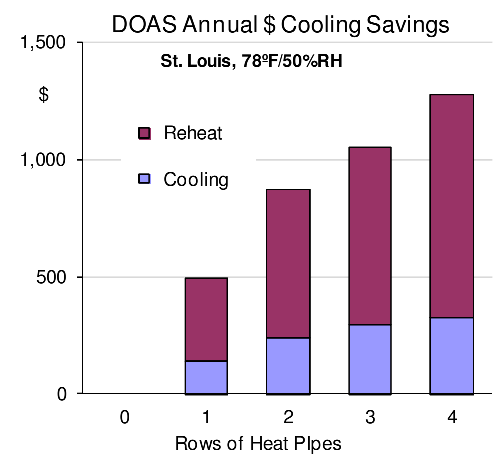

FIGURE 5

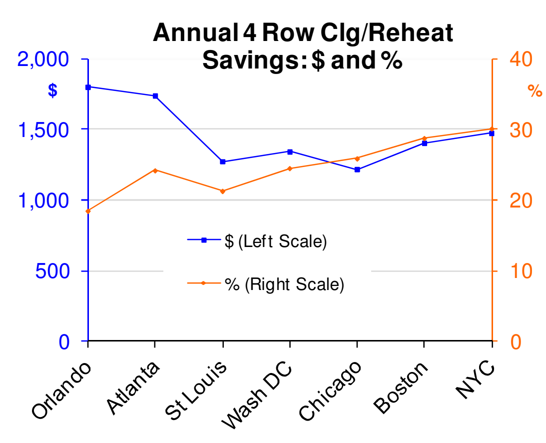

FIGURE 6

15% annual savings with the two row heat pipes and 21% savings with the four row heat pipes compared to no heat pipes. Also note that as the rows increase, the savings are at a diminishing rate, which is typical for plate fin and tube heat exchangers. The reheat savings are higher than the cooling savings, which also mirrors the author's experience due to the relative utility costs and plant efficiencies.

Geographic variation from the model and program is shown in FIGURE 6. As expected with the most run hours, the southeastern cities show the most savings, but the northeastern cities also did surprisingly well, and even better than the southeast on a percentage basis.

As we increase the rows of heat pipes and the zone dry bulb set point at a constant 50 %RH (FIGURE 7), the savings compared to no heat pipes also increase but on a diminishing rate basis. However, the savings for a given number of rows remains essentially the same. This is to be expected since the heat pipes are a dehumidification enhancement.

However, as the number of rows of heat pipes and the zone %RH increase at a constant 78 ºF DB set point (FIGURE 8), we see some interesting results. A higher %RH level requires less reheat, which produces less reheat and cooling savings. Also note that the lower %RH settings save proportionately more.

Lastly, FIGURE 9 reports on the all important economics for 4 row heat pipes. While 2 row heat pipes can be expected to have slightly shorter simple paybacks, the building owner will be footing a little higher energy bill each month as shown in FIGURE 5.

As all the other program variables listed in the APPENDIX were changed (including utility costs, efficiencies and more), the results were as expected and are not reported on here.

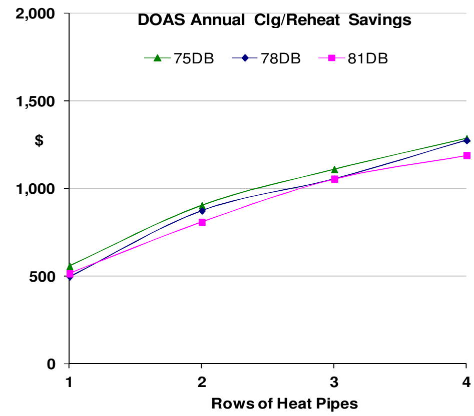

FIGURE 7

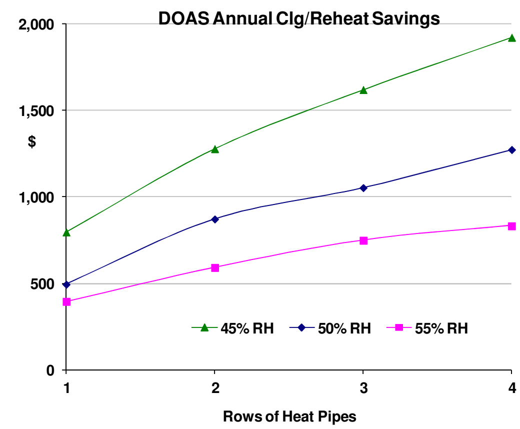

FIGURE 8

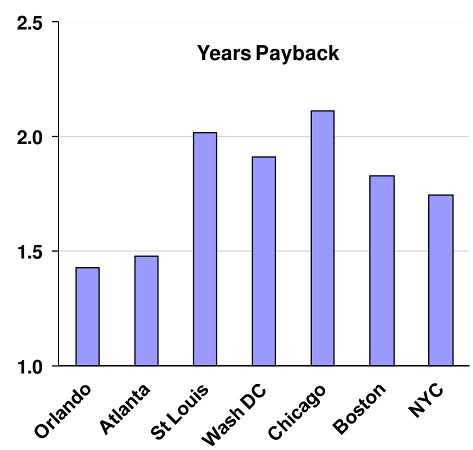

FIGURE 9

GIVEN THAT AN AAHX MAKES "CENTS" FOR DEHUMIDIFICATION, WHICH IS THE BEST?

AHRI Standard 1060 – 2011 recognizes three types of AAHX for heat/energy recovery applications: heat pipe heat exchangers, plate heat exchangers and rotary heat exchangers. The sensible heat version of each of the first two and the total energy version of the last are used in their dehumidification role. While each will have applications where it is clearly the most economical solution, heat pipes on balance present the most overall favorable characteristics in their dehumidification role. Here's why:

1. The wrap around heat pipes can be easily modulated as discussed above.
2. The Recovery Efficiency Ratio (RER) of wrap around heat pipes is superior to all other types of wrap around AAHX[6].
3. The physical space required in an AHU for wrap around heat pipes is far less than all other types of wrap around AAHX. The heat pipes are formed into shape to fit the AHU rather than the air flow path of the AHU having to be heavily modified and increased, especially as the air flows increase over 10,000 CFM and the turning radii increase. The heat pipes are also rectangular in form, more suited to an AHU and already match the form of the various other heat transfer coils.
4. The wrap around heat pipes are the easiest to clean, and in fact duplicate what maintenance personnel must already do for the other coil surfaces in the AHU. Special or new cleaning techniques are not needed with heat pipes.
5. Heat pipes are inherently the most reliable, since they have no moving parts.
6. While hot gas reheat does not strictly speaking fall into this category, it is sometimes used in DX DOAS. The wrap around heat pipes are preferred to HGR because the heat pipes provide pre-cool savings and HGR does not.

SOME PRACTICAL SUGGESTIONS ON INCORPORATING HEAT PIPES

Here are several practical suggestions to make your DOAS the best it can be!

First, the heat pipe effect is easily modulated by either controlling the refrigerant flow within the heat pipes or the airflow through the heat pipes. Controlling refrigerant flow is done with multiple solenoid valves or modulating stepper valves (that draw no power except when they're repositioning); the valve type depends on the size and type of heat pipes, but in both cases, gradual modulating control is available rather than just two position control.
Airflow through the heat pipes is controlled by Face and Bypass (F&BP) dampers to direct the airflow 100% through the heat pipes (and 100% through the cooling coil), 0% through the heat pipes (and 100% through the

[6] Recovery Efficiency Ratio was introduced by AHRI in 2003 and is the single most important comparative performance metric for AAHX; a free download of Guideline V "Calculating the Efficiency of Energy Recovery Ventilation and Its Effect on Efficiency and Sizing of Building HVAC Systems" is available from AHRInet.org. Also see "A Primer on Recovery Efficiency Ratio" by Brooke available at heatpipe.com, as well as other references soon to be published.

cooling coil), or anywhere in between (and 100% through the cooling coil). Both face (across the face of the heat pipe coil) and bypass (for the bypass around the heat pipe coil) dampers are needed to insure the correct flow pattern, because one of the unusual aspects of heat pipes is that as the airflow through it decreases, the Effectiveness rises (but the BTUH transferred is still reduced), and the temperature delta T also rises, somewhat otherwise reducing the desired mixed air result. The interlocked F&BP dampers use standard actuators. It's a matter of convenience within the AHU whether the dampers are installed on the pre-cool or reheat heat pipes (but they're only necessary on only one), as it is whether the bypass dampers are installed above the face dampers or beside the face dampers. Sometimes, the bypass damper is mounted beside the face damper on the reheat heat pipe with the reheat heat pipe have a shorter fin length to accommodate the bypass air flow.

With upfront thought, the airflow path through the Air Handling Unit can be engineered so that using dampers to bypass air around the heat pipes will reduce the airside pressure differential the fan has to work against, thus saving brake horsepower. Therefore, if space is available, controlling the heat pipe effect by airflow is preferred over refrigerant flow. Both internal and external face and bypass dampers have been available as an option on all commercial grade AHUs for decades, and are quite easily incorporated into custom industrial grade AHUs, even expected because of the generally larger airflows and more significant pressure drop energy savings.

Second, one characteristic of wrap around heat pipes is that, as the dry bulb temperature of the air entering a given pre-cool heat pipe reduces (say, as the ambient decreases), the amount of free reheat is also reduced. The amount of decrease is governed by the reduction in enthalpy. There are, however, situations when the DOAS could utilize more reheat than what is available, so not as much energy is saved as there could be. This is when over-sizing the heat pipes at design conditions can help (FIGURE 10). Then, at any point on the part load curve, the oversize heat pipe provides more energy savings than the standard selection.

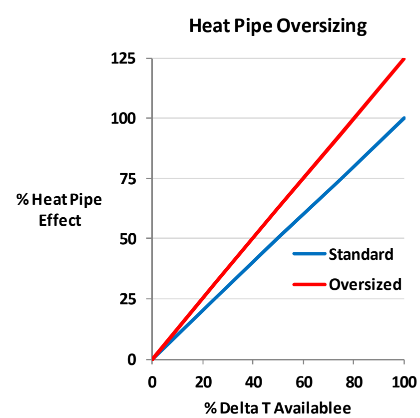

FIGURE 10

Third, today's Building Automation Systems (BAS) allows unprecedented control over the operation of a DOAS, not just in control but also in monitoring, trending, alarms, etc. Following the logic of heat pipe control previously provided in this paper should allow a detailed control scheme personalized to the precise application. The primary concept of wrap around heat pipe use in DOAS is to use as much reheat in the OA conditioning unit as possible, until the first terminal unit calls for cooling per its individual zone set point. The engineers at Heat Pipe Technology would be pleased to review individual control schemes.

CONCLUSION

It should be clear by now that modulating wrap around heat pipes should be used in all DOAS applications. Heat Pipe Technology has been engineering and manufacturing heat pipes longer than any other company, specializes in manufacturing only heat pipe systems, and has introduced all the heat pipe advances available today. Heat Pipe Technology supplies heat pipes to all equipment manufacturers so any preferred equipment manufacturer may still be specified. Turn a good DOAS into a great DOAS with wrap around heat pipes, and make it the most energy efficient and economical system available, bar none!

APPENDIX – NOTES ON THE COMPUTER MODEL AND PROGRAM

<u>Engineering figures used; in all cases, they are from the original third party article:</u>

- 1,649 OA CFM; 78 ºFDB, 50 % RH
- .80 System kW/ton cooling efficiency (includes condenser and AHU fan motors and pumps)
- .80 heating efficiency
- $.125/kWh, $1.25/therm

<u>Other estimates made by the author</u>

- VAV terminal unit
- St. Louis BIN, retail hours

<u>Independent Variables</u>

- OA Conditioning Unit
    - BIN data (location)
    - Hour profiles
    - Rows of heat pipes
- Terminal Unit (TU)
    - RA DB
    - RA %RH
- General
    - Cooling and heating efficiencies
    - Utility costs
    - Sensible loads*
    - Latent loads*

      *While these were defined in the original third party article, they were set up as variables in the program to do additional analyses

<u>Dependent Variables</u>

- OA Conditioning Unit
    - CA DB
    - Sensible cooling
    - Latent cooling
- Terminal Unit (TU)
    - Sensible cooling
    - Latent cooling
- General
    - Total MBTU/Yr
    - Total energy cost

<u>Program Logic</u>

1. The original third party article defined the system layout, and sensible and latent loads
2. The OA conditioning unit CA DP is reset to meet the entire latent load
3. The TUs adjust leaving air temperature for a dry coil, then the CFM to meet the sensible load
4. 3ºF for motor heat reheat and heat pipe airside pressure drop are included