TODAY'S PARADIGM FOR HEAT RECOVERY - PART 2

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INTRODUCTION

Part 1 of this Webinar by the same name and conducted by Engineered Systems magazine was held on April 11, 2012. Archived copies of both Part 1 and Part 2 webinars are available[1], as well as white papers supporting both Part 1 and Part 2[2]. Part 1 explained that today's paradigm for Air-to-Air Heat Recovery (AAHX) from the exhaust to outside air in a coil configuration now includes these four relatively recent models within the paradigm:

This paper supports a webinar by the same name conducted by *Engineered Systems* magazine on July 14, 2012, and sponsored by Heat Pipe Technology.

1. An efficiency metric called Recovery Efficiency Ratio (RER) has been added to AAHX's evaluation criteria. It goes beyond Effectiveness as it measures the energy saved divided by the energy required to obtain those savings, including not only airside pressure drop but also all peripheral energy losses like purge, air leakage, and pump energy. It's similar to EER and kW/ton for unitary and applied equipment respectively.
2. Beyond the traditional adjacent counter air flow design, three additional types of heat pipe systems are now being specified:
    a. adjacent airflow, parallel design (design optimized for parallel airflow instead of counter)
    b. separated airflow with either counter or parallel air flow (condenser vertically above the evaporator in the winter)
    c. pump assisted systems (condenser vertically below the evaporator in the winter)
3. Heat pipes can selectively replace enthalpic AAHX.
4. By any efficiency, effectiveness, or reasonable economic measure like Life Cycle Cost except first cost, the heat pipe is superior to run around coils for all applications less than 100 ft apart.

Part 2 of this series delves deeper into model 3, namely, that heat pipes can selectively replace all types of enthalpic AAHX, including energy wheels and membrane plates. The subject is treated in this separate Part 2 because of its technical depth and major update to the traditional boundaries for the different types of AAHX usage.

In Section 15 (Mechanical) of the Building Specifications, the HVAC system designer is constantly balancing the pros and cons of different components to best meet the sometimes competing system objectives of the building owner within the allowed budget. Classical examples include judging the relative values of capital cost, energy efficiency, maintenance costs and reliability. This paper highlights the facts that, first, a sensible heat pipe AAHX can indeed be used instead of a total energy AAHX for selected exhaust air (EA) heat recovery applications, and that, second, here are the benefits that will be gained at the expense of particular trade-offs. Isn't it better to know there are alternatives and what would be gained and lost than to not even know that the alternative exists?

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[1] http://heatpipe.com/HomePage/Webinar/Webniar&Presentations.html
[2] http://heatpipe.com/HomePage/mktg_materials/Papers.html

Accordingly, the analysis of deciding whether to replace an enthalpic AAHX with a sensible heat pipe is best organized from three important perspectives:

1. Why? What are the benefits and trade-offs of making such a choice?
2. How to still meet building standards and codes
3. Certain aspects of the decision that can best be judged from experienced engineering.

WHY?

Let's recognize that we're not dealing with a brand new concept or product here. Heat pipes have been used for decades in important applications like medical, manufacturing, laboratories and others. There are solid reasons why heat pipes have earned their place in those critical applications, so it's not surprising that their use would eventually trickle down to standard commercial applications. Our starting point then for answering the question is to examine the history-proven benefits and trade-offs of using heat pipes in place of enthalpic AAHX for exhaust air energy recovery.

First, heat pipes have no moving parts so they are inherently more reliable with no emergency breakdowns, catastrophic failures, less maintenance, and longer service life. If the central plant isn't sized to maintain set point conditions if the energy recovery fails, what happens? What happens if a central plant's growth hasn't kept pace with the company's growth, and energy recovery fails? Are maintenance staffs being increased and better trained today than before? Considering these and similar types of questions have pushed the once mundane topics of maintenance and reliability to the forefront of decision making, usually surpassing energy costs in importance.

Figure 1

Second, heat pipes are used in many fields besides HVAC, and they'll function well to over 50" of water column pressure differentials between the two air streams. While a differential this high would be unusual in an HVAC system, there are two inherent byproducts of this feature that are very important:

1. Outside air (OA) and EA fan locations, or more specifically where there are negative and positive fan pressures, can be totally disregarded. Unlike with enthalpic AAHX, the designer doesn't have to be concerned with locating the high and low pressure zones to minimize the differential pressure between the two airstreams at the point of the AAHX.

2. Related to point 1, there is no possibility of cross contamination from the exhaust air stream to the fresh outside air stream.

Third, heat pipes are more efficient than energy wheels as shown in Figure 2. As discussed earlier, the efficiency measure used for AAHX is Recovery Efficiency Ratio.

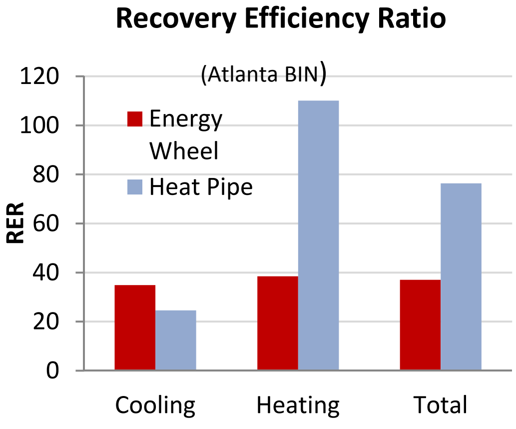
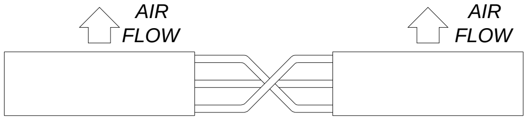


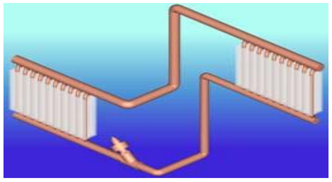
Figure 2

Fourth, most AAHX are installed in air handling units (AHU). Wheels are circular in cross section but heat pipes are rectangular like coils and better fit the AHU geometry with less wasted space, which translates into a reduced mechanical room footprint.

Fifth, the basic heat pipe has no electrical connections so installation and maintenance costs are further reduced.



Sixth, in addition to the traditional basic design of adjacent counter airflow, heat pipes are also designed for adjacent parallel airflows, and any relative airflow configurations separated by up to 100 ft[3] as shown in Figure 3. Wheels are limited to adjacent counter airflows often needing additional ductwork which causes a considerable loss of mechanical or operational space. Five thousand CFM airflows are insignificant, 20,000 CFM airflows mean headaches, and 60,000 CFM airflows are near impossibilities. Further, the additional designs for heat pipes mean that additional building configurations can now be considered for energy savings.



Seventh, special commercial and industrial grade coatings are available for heat pipes in corrosive, toxic and other specialized applications. The materials of construction match the cooling and heating coils, including copper fins and several grades of stainless steel casing.

Eighth, the heat pipe component of an AHU has a lower capital cost than the energy wheel component, usually by over 10%.

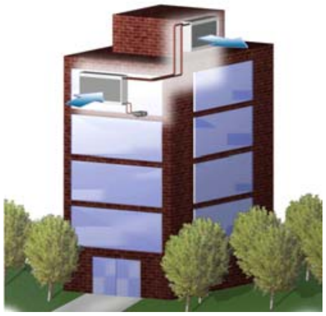


Figure 3

However, energy wheels excel in two areas:

First, while heat pipes only transfer sensible energy, energy wheels transfer both latent and sensible energy. The sensible and latent transfer amounts are roughly the same so generally the wheels transfer twice as much energy.

Second, effectiveness measures the % energy actually transferred by an AAHX out of a theoretical maximum given the conditions. The effectiveness of wheels ranges up to 80% while heat pipes top out around 65%.

There are many not easily quantifiable benefits of heat pipes to be balanced against the relatively easily quantified energy benefits of energy wheels. In the total analysis, it’s important to take the pains to establish realistic values for the heat pipe’s relevant benefits to a particular project.

STANDARDS AND CODES

Part 1 of this webinar series reviewed the applicable Standards and Codes at length[4], and the conclusions are summarized here. While there are many exceptions for particular applications, the general application of comfort conditioning is the basis of the following discussion. There are two key clear mandatory requirements for general exhaust air energy recovery.

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[3] Brooke, Tom. Today’s Paradigm for Heat Recovery, Part 1, April 2012. www.heatpipe.com

[4] Ibid

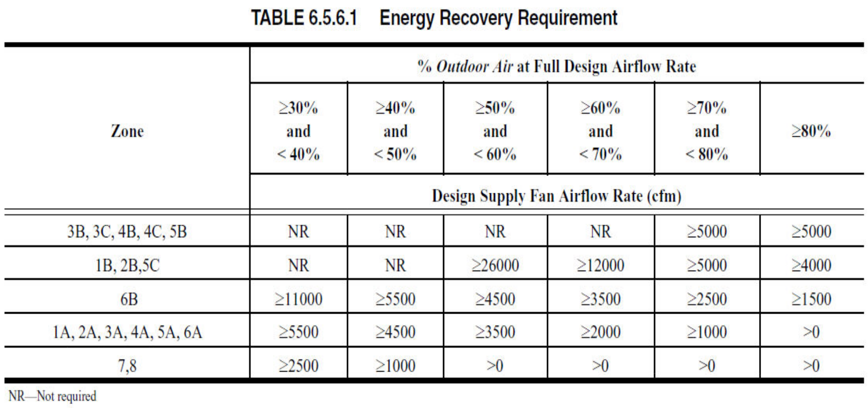

TABLE 6.5.6.1 Energy Recovery Requirement

Zone	% *Outdoor Air* at Full Design Airflow Rate					
	≥30% and < 40%	≥40% and < 50%	≥50% and < 60%	≥60% and < 70%	≥70% and < 80%	≥80%
	Design Supply Fan Airflow Rate (cfm)					
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	≥5000	≥5000
1B, 2B,5C	NR	NR	≥26000	≥12000	≥5000	≥4000
6B	≥11000	≥5500	≥4500	≥3500	≥2500	≥1500
1A, 2A, 3A, 4A, 5A, 6A	≥5500	≥4500	≥3500	≥2000	≥1000	>0
7,8	≥2500	≥1000	>0	>0	>0	>0

NR—Not required

Figure 4

First, paragraph 6.5.6.1 of ANSI/ASHRAE Standard 90.1–2010 specifies the minimum supply fan airflow rates that must have exhaust air energy recovery. They're a function (Figure 4) of the supply air (SA) airflow CFM, the per cent OA of SA CFM, and the climate zone in which the facility is located. The requirements are clear and if the project has an HVAC system that meets the criteria, exhaust air energy recovery must be included.

Second, the same paragraph defines the degree of energy recovery effectiveness by specifying the requirement for 50% 'Total' Effectiveness. However, it wisely does not specify any particular types of AAHX for any application. 'Total' Effectiveness is correctly defined as the change in enthalpy from the Outside Air (OA) design conditions to the Return Air (RA) or EA design conditions. Since Total energy is the sum of latent energy plus sensible energy, the 50% can come from an all latent change, an all sensible change or any combination of the two. The fact that the energy change can be all latent, all sensible, or any combination (as long as the change in total effectiveness is at least 50%) is an important subtlety of the Standard.

EXPERIENCED ENGINEERING JUDGMENT

Of course, our design decisions are not made with blinders on. We're aware of the building codes, but we're also aware of circumstances unique to particular projects and other pertinent background information that will have an effect on the exact type of equipment specified. Following are several relevant professional documents that bear on these types of questions and answers.

First, the same paragraph in Standard 90.1 does not distinguish between summer and winter, i.e., "Is the requirement for.50 total effectiveness during winter or summer design conditions?" The distinction is very important because, while enthalpic devices have the same total effectiveness for summer and winter, sensible transfer devices do not. The winter total effectiveness for AAHX that transfer only sensible energy is ten to twenty percentage points higher than for summer design conditions. It must also be recognized that a project may require a particular benefit(s) that is best fulfilled by a sensible transfer device, and that certainly ASHRAE has no interest or desire to try and regulate whether an enthalpic or sensible transfer AAHX is used. That would not be fair. So does that mean that if a sensible device is used, the winter effectiveness must then actually be a minimum of .65?

Another gray area presents itself. Certainly, all recognize that nationally most EA energy recovery savings come during winter. Even with economizer operation, that's because there are many more hours of winter operation with a temperature difference between the OA and RA, and that temperature differential is also larger during winter than summer. So does one make decisions based only on winter savings and neglect the summer savings (maybe in some zones, but which zones exactly)? Or perhaps it's best to look to the total winter and summer savings. Or, most appropriate in the author's view, could the decision be based on whether the winter or summer effectiveness provides the higher BTU savings at the facility's location?

The author has requested an informal interpretation of these types of questions from the 90.1 committee chair, and has received an acknowledgement of the situation and my request for an informal interpretation. This paper makes no further judgment on the committee's intentions or actions.

Whatever the decision, the designer should be aware of the well known psychrometric process Indirect Evaporative Cooling (IDEC)[5]. This boosts the energy recovery performance only during summer conditions. For example, given a particular heat pipe's winter performance of .50 total effectiveness at Baltimore's 1% design conditions, the total effectiveness of the same heat pipe during summer's 1% design condition is .33 without IDEC and .55 with 80% IDEC.

Second, the primary question before us is "Notwithstanding the benefits, does it make fundamental good engineering sense to use a sensible heat pipe instead of an enthalpic energy wheel to precondition the OA?" Answering this question requires answering other questions first:

1. Of course, the end result of conditioning the OA is to get it to adequate comfort conditions. But what is adequate?
2. And how do the heat pipes comparatively perform across the myriad of weather conditions throughout North America?

Figure 5.2.1.1 of ANSI/ASHRAE Standard 55 – 2010 (Figure 5) defines the indoor human comfort range for typical comfort conditioning applications. Blue is for winter and red is for summer. While the dry bulb temperature extremes and the upper absolute humidity level of .012 lbs water/lb dry air (61.5 ºF dew point) are very specific, there is no lower relative or absolute humidity level defined. However, in practice we know that a 0% RH has other non-comfort implications like static electricity, is barely achievable, and certainly costs more. The two red lines in FIGURE X will be explained shortly.

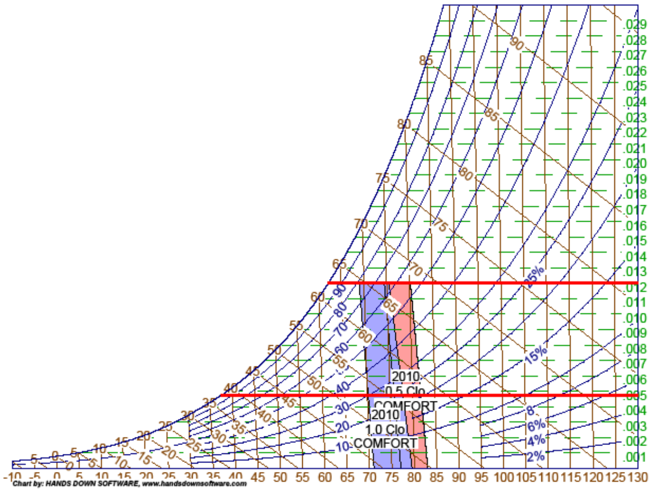

Figure 5

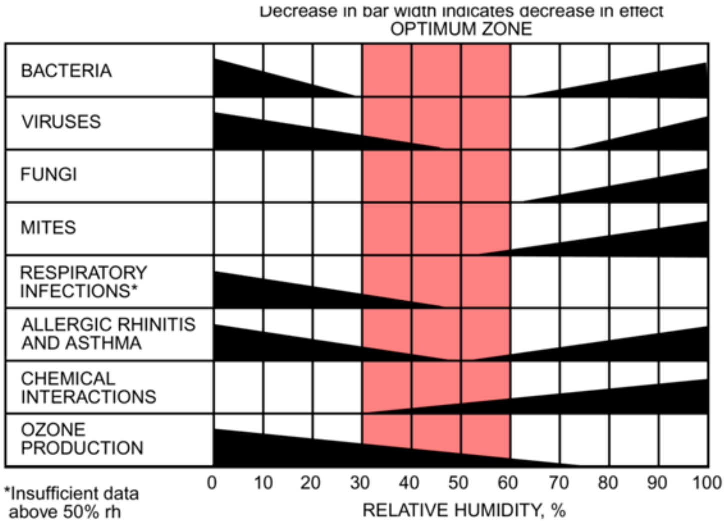

Figure 6

One of the most famous antecedents upon which many of today's codes ultimately rely is the "Sterling" chart in Figure 6[6]. This chart came from a scientific paper published in 1985 and, while not totally quantitative, was one of the first to completely survey the science done so far. It defines the proper relative humidity to be from 30% to 60%. The authors readily acknowledge there are a multitude of exceptions, but it is proper for general comfort conditioning.

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[5] Brooke, Tom. "Indirect Evaporative Cooling with Heat Pipes". January, 2012. www.heatpipe.com

[6] Sterling, E.M., A. Arundel, T.D. Sterling. 1985 "Criteria for Human Exposure to Humidity in Occupied Buildings." ASHRAE Transactions, Vol. 91, Part 1B, pp. 611-622.

Combining these two documents allows us to establish the reasonable minimum and maximum dew points for comfort conditions in Figure 7. The former is the minimum 30 %RH from Sterling at the lowest dry bulb per Std 55, and the latter is the center summer dry bulb at the .012 lb/lb set by Std 55. For our purposes, these two dew points also define the OA minimum and maximum absolute humidity levels, above and below which respectively there is minimum need for AAHX latent addition or removal; these are marked as the red lines in Figure 5. That need then establishes the best geographical locations for heat pipes. Now that we have a measuring metric, how can we use that geographically?

Min/Max Dew Points	**Psychrometric State Point**
Minimum	70.5 ºFDB/30 %RH/.0047 lb/lb/37.5 ºFDP
Maximum	78.0 ºFDB/60 %RH/.012 lb/lb/61.5 ºFDP

Figure 7

For that, we first look to ASHRAE Standard 90.1 – 2010's Climatic Zones. Figure 8 shows that there are eight different zones in North America, and each of the eight can be divided into from one to three zones depending on its prevalent moisture level. Altogether, there are fifteen distinctly different climatic zones.

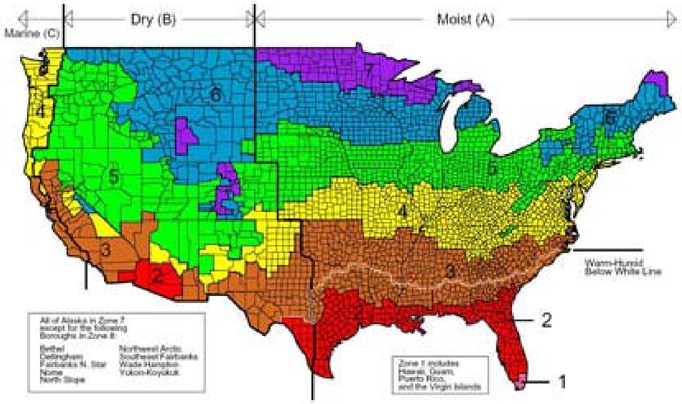

Figure 8

A 2009 PNNL report[7] sponsored by the Department of Energy lists the most appropriate city within each zone that best represents and balances the representativeness of its climate and its number of commercial buildings. The cities designated as best representative for the different zones are listed in Figure 9.

Climate Zone	**City**
1A	Miami
2A	Houston
2B	Phoenix
3A	Atlanta
3B	Los Angeles
3C	San Francisco
4A	Baltimore
4B	Albuquerque
4C	Seattle
5A	Chicago
5B	Denver
6A	Minneapolis
6B	Helena
7	Duluth
8	Fairbanks

Figure 9

Recalling our objective then, we want to examine how a project location's annual weather data (defined by the fifteen cities cited as typical for their zones in Figure 9) or, more precisely, each of the location's annual hour's average temperature and absolute humidity, may or may not fall within the newly established, reasonable minimum and maximum humidity levels. This is done by plotting annual hourly weather data on a psychrometric chart with both the ASHRAE Standard 55 comfort conditions already on it and the minimum and maximum absolute humidity levels established by the reasonable Indoor design conditions for comfort as shown in Figure 5.

Annual hours to the right and left of the comfort zones indicate that sensible heat transfer from the OA or to the OA respectively is needed. But since that heat is sensible, it's recognized that function can be performed equally well by sensible type recovery devices such as heat pipes. Our interest is really in those points above the upper and below the lower red horizontal lines, as those represent the maximum and minimum absolute humidity levels respectively for human comfort conditions. Other protocol used in developing these results are:

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[7] Liu, B., Thornton, B.A., Wang, W., Rosenberg, M.I. September 2009. "Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings". Pacific Northwest National Laboratory – 19004.

1. Typical Meteorological Year 3 (TMY3) data is used as those weather observations are the most recent and represent averages rather than extremes.
2. If the number of hours above the maximum absolute humidity level is greater than 1% of the total annual hours, than that climate zone is designated as less desirable for a sensible exhaust air energy recovery device.
3. The hours below the minimum absolute humidity level are also shown for each location for reference.
4. Different types of facilities have different operating hours, so each type of facility's hours are noted according to FIGURE X and then only those hours are plotted. This is a fairly common variable in weather and psychrometric programs. The Code is the superscript in Figure 10.

Profile	Specific Hours	Annual Hours	Code
Full Time	All Hours	8,760	F
Retail Hours	Sat-Sun, 9am-10pm	4,745	R
Office Hours	Mon-Fri, 8am-6pm	2,610	O
K-12 School Hours	Mon-Fri, Sep-Jun, 7am-5pm	2,170	K

Figure 10

When the data plots are made, analysis shows that there are the two clear different groupings as shown in Figure 11. Four of the typical data plots are shown in the following section, and those straddle the different hours of operation, priorities, and climate zones. Please see the separate lengthy APPENDIX, also downloadable from heatpipe.com, for essentially all plots not included in the body of this paper's discussion.

Climate Zones	
Higher Priority	**Lower Priority**
All Hours Within ASHRAE Std 55's Comfort Humidity	Significant Hours Above ASHRAE Std 55's Comfort Humidity
2B^{K}, 3B^{FR}, 3C^{FROK}, 4B^{FROK}, 4C^{FROK}, 5B^{FROK}, 6B^{FROK}, 8^{FROK}	1A^{FROK}, 2A^{FROK}, 2B^{FRO}, 3A^{FROK}, 3B^{OK}, 4A^{FROK}, 5A^{FROK}, 6A^{FROK}, 7^{FROK}

Figure 11

What about humidification in the winter? For backup capability, most central plant HVAC systems (cooling, heating, dehumidification, and humidification) are sized as if the AAHX were not installed. Therefore, there is no additional capital cost for winter humidification. However, when a heat pipe is used for energy recovery, there will be a slight increase in the HVAC system's operation cost for those hours at the lowest level of absolute humidity. If any humidification is needed, no type of AAHX can provide all that's needed.

Let's repeat the question before us: "Notwithstanding the benefits, does it make fundamental good engineering sense to use a sensible heat pipe instead of an enthalpic energy wheel to precondition the OA?" The fact that 27 out of 60 climate zone/working hour combinations, or nearly half, already have all their working hours within the absolute humidity limits established by ASHRAE Standard 55-2010 is ground breaking and shouts that the answer is "Yes!." These are the geographical locations waiting to receive the benefits of the simpler heat pipes in exhaust air energy recovery applications with open arms. It's of course recognized that further sensible heating and cooling will be necessary by the heating and cooling coils respectively, but that's the case for any type of AAHX.

TYPICAL PLOTS

Following are four typical plots spanning the variables of priorities, operating hours and climate zones. The first plot is for Climate Zone 4C as represented by Seattle. School operating hours are plotted and it's clear that those operating hours require a minimum, if any, of moisture removal, making this climate zone and those operating hours a high priority for heat pipe exhaust air energy recovery.

On the other hand, Figure 13 is a plot of the annual office hours for climatic zone 4A as represented by Baltimore. There are a large number of hours beyond the absolute maximum humidity level, indicating significant moisture removal effort is required. Sensible AAHX rarely remove moisture from the supply outdoor air in an exhaust air energy recovery application, so there would be slightly increased operational costs. That's not to say this location's economic analysis shouldn't be analyzed for heat pipes, because in fact the benefit of reliability may be economically overwhelming for a particular application. But relatively speaking, climatic zone 4A is generally designated as a lower priority location.

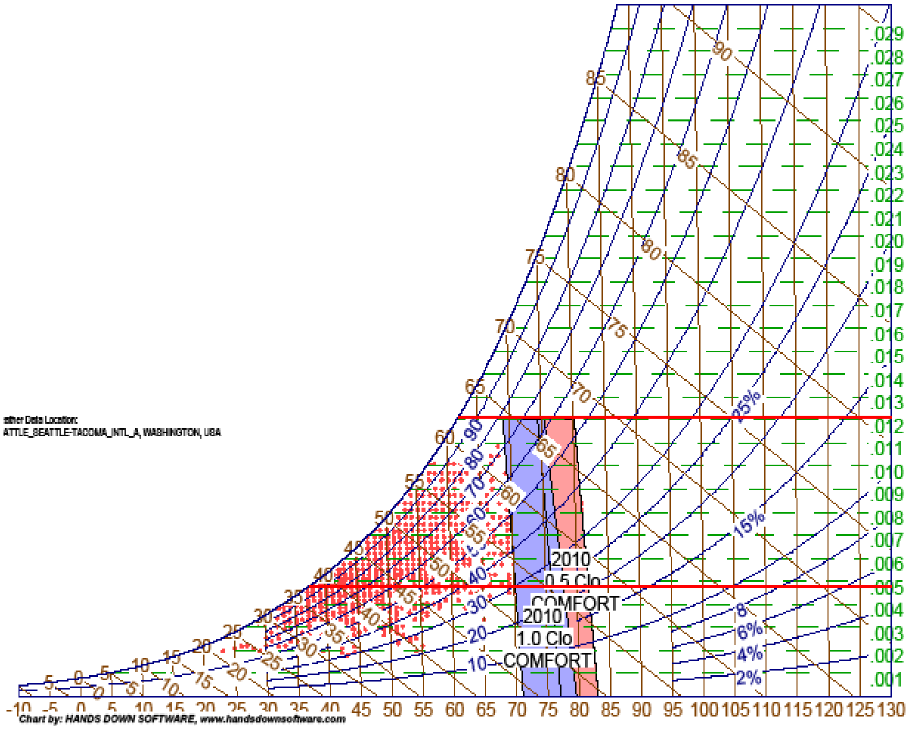

Figure 12

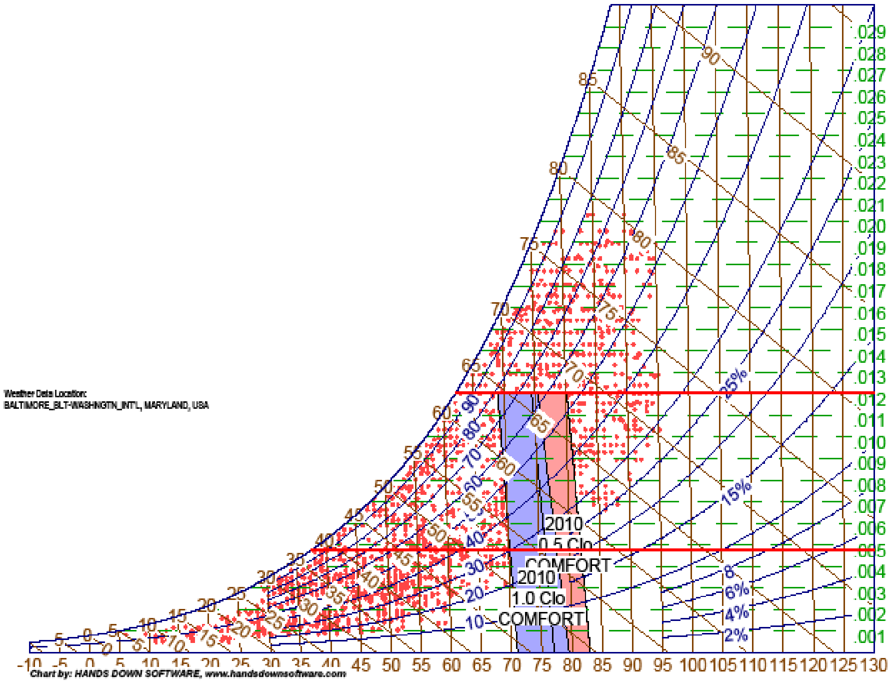

Figure 13

The third typical plot (Figure 14) is for retail hours in the 3B climatic zone as represented by Los Angeles. This plot has some operating hours above the maximum absolute humidity level, but the number is less than 1% of the total hours. This climate zone is categorized as a high priority. However, note that if the operating hours were for a school or office, the zone would be categorized as lower priority; this shows that the operating hours do in fact play a lead role in the priority selection of the type of AAHX. Please also note that these distinctions are at a national level and have no tie to the different types of HVAC systems that may be locally proven and preferred for the different types of operating facilities.

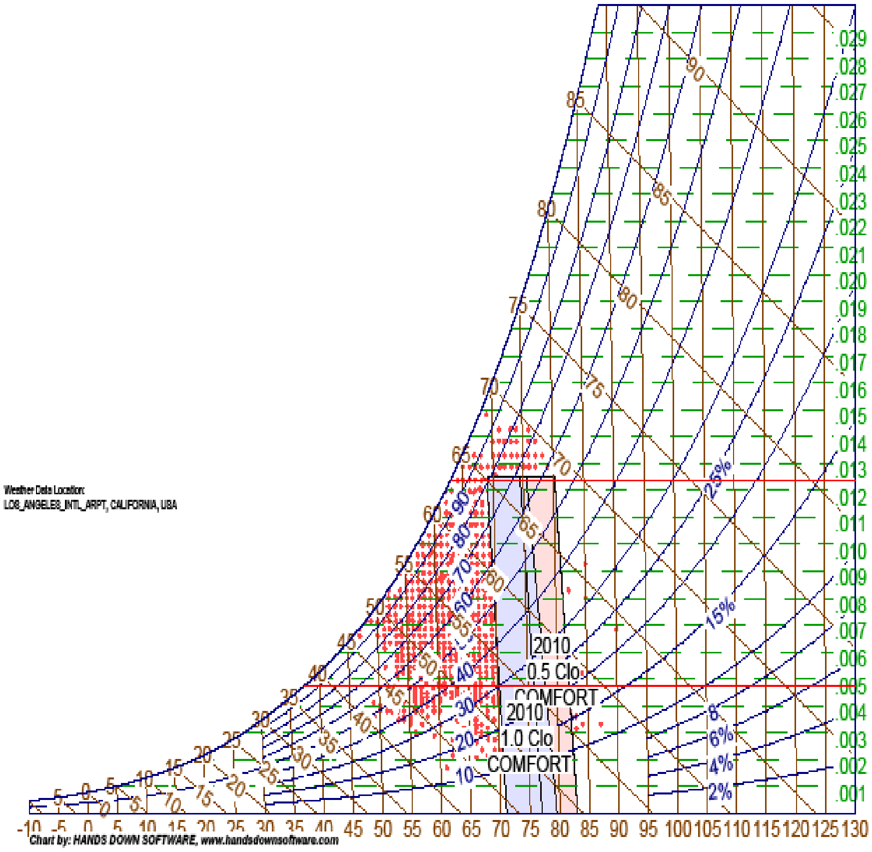

Figure 14

Lastly, Figure 15 is a plot of the full (8,760) annual hours for climate zone 3C as represented by San Francisco. There are no hours when the outdoor air absolute humidity is higher than ASHRAE Standard 55's recommendation, and this climatic zone is a high priority item for all different types of operating hours.

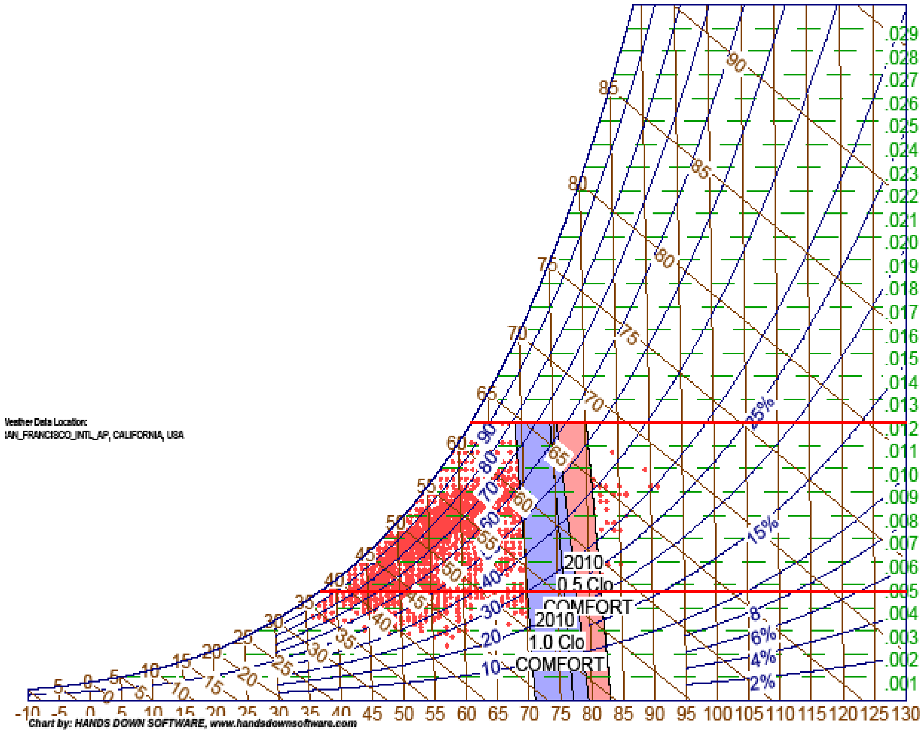

Figure 15

CONCLUSIONS AND RECOMMENDATIONS

This analysis has led to the conclusions that:

1. Almost half of North America's climate zones are excellent locations for sensible heat pipe exhaust air energy recovery, just from a fundamental engineering perspective.

2. Further, if one highly but realistically values one or more of the heat pipe's singular benefits such as extreme reliability for a given facility, then heat pipes in the other climate zones can also make economic sense.

When all the factors are reduced to economics, it's easier to understand the trade-offs that have unconsciously been made, and to then reprioritize the relative important benefits of the various types of AAHX.

It is clear then that the heat pipes should be considered for all exhaust air recovery projects, but especially for those in the high priority climate zones. But how, exactly, does one proceed?

1. Understand heat pipe's many benefits compared to enthalpic AAHX and how they apply to a particular project.
2. As best can be done, quantify them. Note that many (reliability, no catastrophic failure, no cross contamination, longer service life, less maintenance) likely have values an order of magnitude greater than energy savings.
3. Determine the additional energy saved by an enthalpic AAHX. Note that while the Effectiveness is often lower with heat pipes, their Efficiency (RER) is always higher.
4. Understand and use the location priorities established earlier. Include the facility's operating schedule in the analysis.