A Primer on Recovery Efficiency Ratio

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INTRODUCTION

As well it should be, probably the most used metric in the applied HVAC equipment industry is the concept of *Efficiency*. Not only must equipment physically form, fit and function in its application, but the owner, our own design professionalism and competitive forces usually end up providing equipment that provides the most MBH output with the least kW input that the budget allows. Sure, there are those situations or features that sometimes make one piece of equipment especially well suited for an application, but its energy use is the major contributor in its Life Cycle Cost.

This is the first of three articles examining the Recovery Efficiency Ratio and its implications for the different types of Air-to-Air-Heat-Exchangers. This article introduces the concept and applies it to heat pipes.

Efficiency is defined as the ratio of power output divided by power input; for a given amount of input power, a higher output power will be measured by a higher *Efficiency*. Depending on equipment type, the units of *Efficiency* may be either dimensionless (COP) or not (EER, kW/ton). The concept is so important that not only is equipment rated at the design condition but also often at a predefined series of conditions along the equipment's part load curve where it operates 99% of the time.

Figure 1

The American National Standard Institute (ANSI) through the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test standards, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Product Standards and third party testing agencies provide reliable guidance and authority to evaluate *Efficiency*. For example, split systems up to five tons rely on ANSI/ASHRAE Test Standard 37 (2009 latest) to define the test protocol, and ANSI/AHRI Product Standard 210/240 (2008 latest) to define Rating Conditions and report manufacturer's *Efficiency* ratings as certified based on tests conducted by well known national third party testing agencies. Similar procedures are in place for other heavy users of utility power, including Unitary Packaged Equipment and Large Tonnage Chillers. However, until relatively recently, a true universally accepted concept of *Efficiency* as defined above has not been defined and available to users of Air-to-Air Heat Exchangers (AAHX), another vital part of the complete HVAC system.

DEFINITION

As HVAC design professionals and building owners continue to refine their complete system *Efficiency* analysis, the attention eventually boils down to the AAHX. AAHX transfer energy (sensible only, or sensible and latent) in three applications:

1. From an exhaust air stream to a separate fresh air stream. This is an HVAC application used in both heating and cooling and is sometimes called a parallel application. We'll focus on this application.
2. From upstream of a cooling coil to the same airstream downstream of the same cooling coil. This is an HVAC application, is used in cooling applications only, and is sometimes called a series application
3. In process applications, sensible heat is transferred from a higher to a lower temperature air stream.

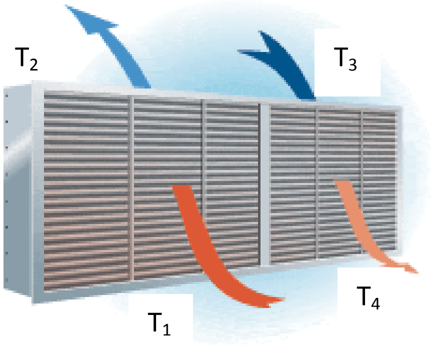

Figure 2

Historically AAHX have only been measured by a different metric, namely *Effectiveness*. *Effectiveness* has proven its worth and been used for many years as the basic performance metric upon which AHRI's third party certified ratings are based. Although similar looking, its meaning is far different from *Efficiency*. *Effectiveness* is defined as the ratio of the difference between the input and output conditions of one AAHX divided by the difference between the input conditions of the two AAHX. The general equation definition of *Effectiveness* is established in both ANSI/ASHRAE Standard 84-2008 and ANSI/AHRI Standard 1060-2011 and is reproduced in this APPENDIX. The equation is necessarily complex as it must include all types of AAHX, but to more easily understand the concept by assuming equal air flows and no condensation, for heat pipes it reduces to *Effectiveness* = $(T_1-T_2)/(T_1-T_3)$.

While *Effectiveness* is an important measure of the AAHX per se, what about from a total holistic system efficiency perspective? Note that the definition of *Effectiveness* does not include any reference to the energy cost of obtaining the saved MBH. So an unsuspecting designer may select an AAHX with a relatively high *Effectiveness*, i.e., good heat transfer, but with a high energy cost. For example, a twelve row deep heat pipe with twelve fins per inch would have a high *Effectiveness* but also a very high airside pressure drop. Perhaps a shallower heat pipe with a lower airside pressure drop would be better, but until recently there was no industry accepted protocol or reference to use for comparison of AAHX, much less any single metric that could be used to compare an AAHX against a totally different system component like a pump. On which components of the total HVAC system does the designer spend the budget to obtain the overall best system? The system designer's responsibility is to be aware of all those potential trade-offs as he strives to design the most efficient system for the budget.

To fill that gap in the AAHX metrics, the concept of *Recovery Efficiency ratio (RER)* was introduced by AHRI in 2003 (ARI then). Called Guideline V[1], it precisely defines *RER* as "the energy recovered divided by the energy expended in the recovery process". Heat Pipe Technology considers Guideline V to be a watershed event in the

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[1] A free copy of Guideline V may be obtained from AHRInet.org; click on standards/HVACR Industry Guidelines/AHRI Guideline V/Free Download

AAHX industry segment because a) it better links energy saved with the energy required to obtain that savings, and b) it accounts for often ignored peripheral energy consumers that are necessary to obtain the saved energy. Now, all the input power must be considered, including:

1. The airside pressure drop through both AAHX; this usually consumes the highest input power
2. The auxiliary power of the wheel drive motor for a rotary AAHX
3. In a rotary AAHX, the reduced air flows as defined by the leaving supply air (not the entering outdoor air which is then reduced because of purge losses
4. The auxiliary power for the glycol pumps in a pumped AAHX system

The full defining equation for *RER* as applied to all types of AAHX may be found in both ANSI/ASHRAE Standard 84-2008 and ANSI/AHRI Guideline V – 2003, and it is also in this APPENDIX. However, since heat pipes do not require any peripheral energy devices, their *RER* can be more simply defined as the BTUH transferred divided by the sum of the two airside pressure drops, all expressed in the same power units (often HP or KW) so a dimensionless ratio results.

Just like *Effectiveness,* a higher *RER* is better. However, *RER* is more sensitive and better highlights the difference when two selections are compared. This magnification is due primarily to differences in the airside pressure drop which is in the denominator of the *RER*.

Guideline V also shows how to calculate the E*fficiency* of the primary cooling/heating equipment combined with the AAHX. Suffice to say here that the author has not run across a single instance of an AAHX being less efficient than the primary equipment, which means adding an AAHX will always increase the total system's *efficiency*.

EXAMPLES AND DISCUSSION

Now we're equipped to look at some examples, somewhat simplified in order to emphasize the principles involved. Along those lines, we'll only change one variable, the face velocity in feet per minute (FPM).

Example 1 – Consider a simple standalone heat pipe EA/OA heat pipe heat recovery application. The Design Conditions are 10,000 CFM of Outside Air entering at 40ºF DB/30ºF WB (T_1 in Figure 3), and 10,000 CFM of Exhaust Air entering at 70ºF DB/50% RH (T_3). We'll use 70% efficiency for fans and the heating plant, and 90% efficiency for motors. Utility costs are \$.10/kWh and \$1.20/therm and there are 1,000 equivalent annual full load operating hours.

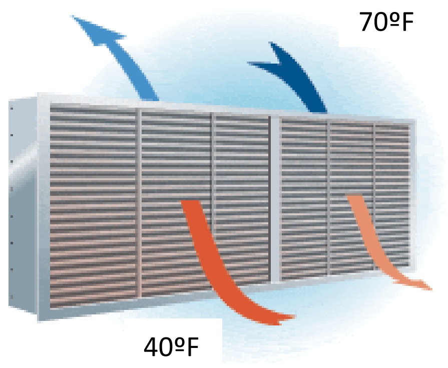

Figure 3

Using a 6 row, 12 fpi heat pipe, the Heat Pipe Technology computer selection program provides the technical performance data shown in Figure 4. For example, using the formula at 350 fpm, the *Effectiveness* is (40 – 57.7)/(40 – 70) = .59.

Fpm	Supply Air ºF DB	Leaving Exhaust Air ºF	% Sensible Effectiveness	MBH Recovered	Airside Pressure Drop " (each side)
350	57.7	52.5	59.0	191.4	.32
500	56.2	54.0	54.0	175.5	.59
650	55.1	55.1	50.2	163.0	.92

Figure 4

To be realistic, capital costs also enter the deliberations at some point, so we'll also incorporate a Price Factor. The Price Factor is the price at the specified FPM divided by the price at 500 FPM, which is an often used face velocity rule of thumb. All pricing is for identical heat pipes except for the face area and includes standard channel markups and installation (40 man-hours plus $1,000 in materials).

FPM	Price Factor	Effectiveness /Price Factor
350	1.22	48.4
500	1.00	54.0
650	.88	57.0

Figure 5

As expected, a slower face velocity results in a higher *Effectiveness*. *Effectiveness* only measures the heat transfer benefit so naturally the alternative with the highest operating benefit without regard to the operating cost associated with it will be selected. However, when pricing is considered, it appears that the 650 fpm selection is best. As the velocity increases, the incremental pricing increases at a higher rate than the *Effectiveness* decreases.

Now we look at the same selections except use the *RER* to determine the "best" selection. The *RER* itself also indicates that the 350 fpm selection is best, the same as *Effectiveness* does. However, note the great discrepancy in the relative values: the *RER* at 350 fpm is over three times higher than at 650 fpm, but the difference is only 17% as measured by *Effectiveness*. That strongly points to the lower face velocity as the optimum. Moreover, opposite to what we found with *Effectiveness* when Pricing was considered, *RER* with the pricing factor still favors the 350 fpm selection. By having the denominator of *RER* report the pressure drop, *RER* reacts strongly to the changing velocity, at a higher rate of change than the pricing. So not only is *RER* more sensitive than *Effectiveness,* but when price is considered we get confirmation because the cost of that energy saving benefit is acknowledged.

FPM	MBH	" PD each side	RER	RER/ Price Factor
350	191.4	.32	47.0	38.5
500	175.5	.59	23.4	23.4
650	163.0	.92	13.9	15.8

Figure 6

But just to be sure, let's run a Life Cycle Cost Analysis (LCCA). For a twenty year cycle, and with the US Dept of Energy's current recommended discount and inflation rates of 3.0% and .9% respectively, we find in Figure 7 that indeed the 350 fpm selection is the optimum.

FPM	Capital Cost $	Annual Operating Utility Savings $	Annual Maintenance Cost $	Present Value of Future Total Savings and Costs $	Net Total Present Value $
350	15,477	1,914	40	34,163	18,686
500	12,706	1,754	40	31,246	18,540
650	11,214	1,630	40	28,986	17,772

Figure 7

Example 2 – Now let's consider heat pipes from another manufacturer. A Competitor's computer selection program produces the results in Figure 8, resulting in the graphical comparison to Heat Pipe Technology in Figure 9. Note that the higher *RER* for HPT's equipment is a function of both a higher heat transfer rate as well as a lower airside pressure drop.

FPM	Sensible Effectiveness	MBH	" PD each side	RER
350	53.3	175	.35	39.3
500	46.7	153	.61	19.7
650	41.9	138	.93	11.7

Figure 8

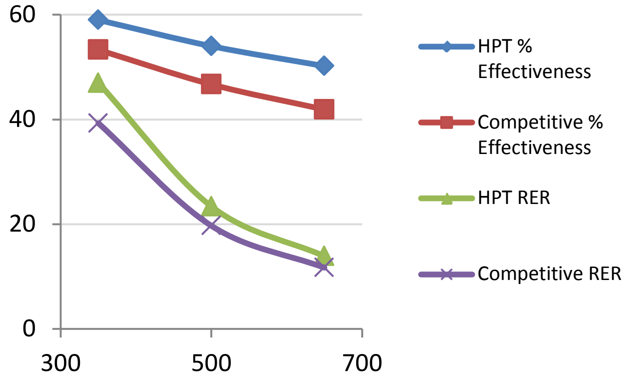

Figure 9

Interestingly, working backwards at the already determined optimum 350 fpm face velocity to obtain the same Net Total Present Value as with the heat pipe manufactured by Heat Pipe Technology, the Competitor's heat pipes would have to be less than free to provide the same LCCA as the heat pipes from HPT. This emphasizes the leading role *RER* plays by highlighting the key technical performance values that reflect the very real economic concerns of the owner! Even the smallest improvement in *RER* is economically important to the owner!

Example 3 – Although Guideline V was developed only for AAHX applications that recover energy from exhaust air to pre-condition outside air, its introduction of *Efficiency* is a valuable analysis tool that can also apply to the same AAHX used in wrap around (or “series” as defined earlier) applications. Recall that the series wrap around application produces two separate energy savings (precooling and reheating; both would otherwise require outside utilities) while the parallel energy recovery application produces energy savings on only one AAHX side. Conceptually therefore, we should expect an AAHX’s wrap around *Efficiency* to be roughly twice as high as the same AAHX used in an energy recovery application.

Sensible Effectiveness %	MBH Transferred	“ PD each side	RER
16	68	.05	106.8

Figure 10

Let’s consider 10,000 CFM of Outside Air at 90/74 and there are 200 equivalent full load cooling hours. The Supply Air setpoint is 58ºF DB/52ºF DP (6ºF of reheat neglecting motor reheat) and the face velocity is 350 fpm. All other variables are the same as in previous examples.

Again, just comparing *Effectiveness* could potentially mislead the system designer. The *Effectiveness* in this wrap around application is only a quarter of that in the heat recovery application. Yet the *RER* is three times higher! And the *RER* of the wrap around heat pipe AAHX is actually over twice the *RER* as used in the heat recovery application. The reason is that whereas the heat recovery application is for 6 rows, the wrap around is 1 row, and incremental rows produce less energy transfer by each row but the pressure drop linearly increases as the rows increase. The lesson here is that if the psychrometric conditions warrant it, the wrap around AAHX can improve the total HVAC system *Efficiency* even more than the heat recovery application!

CONCLUSIONS

Several examples have illustrated the power and versatility of *RER*. It condenses more important technical performance data into a single metric than *Effectiveness*.

Since the Recovery Efficiency Ratio doesn’t take into account the total HVAC system’s efficiency, nor the operating hours at all the different BIN conditions, it can’t be used to judge an AAHX system against no system. It can only compare AAHX *Efficiency* at single operating points.

Nevertheless, Heat Pipe Technology strongly recommends the use of Recovery Efficiency Ratio. Typical construction documents specify performance at one design condition and by combining the energy savings and the energy used to obtain those savings into a single value at that design condition makes it easier for a specifying authority to correctly evaluate differente product offerings, and for a less efficient selection to be weeded out early.

APPENDIX

1. The general equation for Effectiveness E is:

Effectiveness = $[(m_s)(X_1 – X_2)]/[(m_{min})(X_1\text{-}X_3)]$

Where m = mass flow rate

S = Supply Airflow

min = the minimum airflow of the supply and exhaust values

X = Dry Bulb Temperature (ºF), or Absolute Humidity Ratio (lbs water/lb of dry air), or Total Enthalpy (BTU/lb)

Numbered subscripts are the Station Positions as shown in Figure 2

2. The general equation for Recovery Efficiency Ratio is:

RER = $[(E_{net})(m_{min})(X_1\text{-}X_3)]/(Pwr_{blwr} + Pwr_{comp})$

Where Pwr_{blwr}= Sum of blower power required to overcome the static resistance of both AAHX airstreams

Pwr_{comp} = All other component power inputs

Other variables as defined for Effectiveness above