David Sellers

From: David Sellers
Sent: Tuesday, July 24, 2018 6:59 PM
To: Brian Clark (brian.c.clark@usace.army.mil); 'brian clark'; 'Tulley, Jay H CIV (US)'; 'Jay Tulley'
Cc: Ryan Stroupe (R2S2@pge.com)
Subject: RE: Heat Recovery Unit Analysis Spreadsheet

Hi all,

I have inserted stuff below to continue what I was saying when this went off into cyberspace last night.

Also, I mention uploading a spreadsheet and specifically, I uploaded it to the AKO web site and will share the link to that via that utility on the web site when I get done. I have only shared the Ft. Leavenworth specific spreadsheets, but can share the others if you want to see them.

David

Senior Engineer
Facility Dynamics Engineering
Northwest Satellite Office
8560 North Buchanan Avenue
Portland, Oregon 97203
Office - 503-286-1494
Cell - 503-320-2630
DSellers@FacilityDynamics.com
http://www.facilitydynamics.com/
Visit my Commissioning Resources website at www.Av8rDAS.com
View *A Field Perspective On Engineering* and past posts from
A Field Guide for Engineers at http://av8rdas.wordpress.com/
View *The Other Side of Life* at https://av8rdaslife.wordpress.com/

From: David Sellers
Sent: Monday, July 23, 2018 9:54 PM
To: Brian Clark (brian.c.clark@usace.army.mil) <brian.c.clark@usace.army.mil>; 'brian clark' <bcclark.60601@gmail.com>; Tulley, Jay H CIV (US) <jay.h.tulley.civ@mail.mil>; Jay Tulley <jay.tulley@gmail.com>
Cc: Ryan Stroupe (R2S2@pge.com) <R2S2@pge.com>
Subject: Heat Recovery Unit Analysis Spreadsheet

Hi all,

So, some bottom lines on all of this as a starting point, followed by the details behind them.

1. I figure we should share this with the class but thought I would run it by you guys for a sanity check first.

2. The Muir and Flint Energy Recovery Units probably use more energy than they save but generate other savings like demand reduction and first cost reduction.

3. Getting the baffle installed in helped a lot, but not as much as we SWAGGed the night before the presentations (we saved hundreds a year, not thousands a year). But it also should help with the capacity short-fall on design days and reduce demand.

4. There may be a justification for taking steps to balance the flow rates in the units Muir and Flint (as in make the supply flow and exhaust flow the same). There is a lot to think about if you were to consider that, but the over-all effectiveness improves if you can do that, so it may be a good RCx opportunity.

5. This equipment is really complex and has a lot of variables at play. And, they the Energy Wheel is a cog in a really complex air handling arrangement, with even more variables in play.

6. You need to take the manufacturers cost benefit numbers with a grain of salt. There are so many variables in play that you almost have to do some sort of site specific analysis. Ideally, the spreadsheet I developed gives you a tool for doing that.

7. The options/features you chose for your Energy Recovery Unit can radically (order of magnitude) impact the $ per cfm for the unit. I would want a quote from a vendor for any cost benefit assessment I did. All of the "rule of thumb" numbers and even the RS Means numbers are an order of magnitude different from what was spent for the Muir unit based on the data sheet you have.

8. From RS Means data, the $ per cfm cost curves goes near vertical for smaller unit sizes like the ones in Muir and Flint. It seems to flatten out for units in the 10,000 – 20,000 cfm range and larger. In my experience, this is generally true.

9. The term "installed cost" needs to be taken with a grain of salt. It probably does not include things like piping connections, power connections, controls, and the pad the unit is sitting on.

10. The spreadsheet I am using for this is quasi-user friendly. My goal was to make a tool that you could believe in terms of giving you a rough assessment of what to expect from a DOAS unit that captured some of the things that would impact the bottom line that we saw at Ft. Leavenworth; like the missing baffle or the uninsulated exhaust duct for instance.

    I have included a guide to the tabs in the spreadsheet at the end of my annoyingly long e-mail. I feel like the numbers I am getting from it currently are order of magnitude believable when contrasted with the vendor predictions based on their rules of thumb. I will be using it on some Seattle projects to further validate it, but I am pretty comfortable letting others use it at this point, assuming your sanity check of it confirms that and that the understand how to set it up.

11. If you think it would be helpful, I could record a video and make a blog post that focused on this topic and using the spreadsheet. There is a bunch of money left in the budget since the contract was not in place that far in advance of the class and as a result, I was not able to do some of the pre-class stuff we had anticipated. So, my plan is to use it to support things like Don's Carlisle Barracks project and this, assuming you concur. I know that technically, I am working for Ryan, but I feel like if you are O.K. with this stuff, he will also be O.K. with it. Mostly, I don't want to waste money or take advantage of anything.

I am uploading the spreadsheet I have been working on to assess the energy recovery wheel in Muir (or anyplace really) to the AKO site. It is really a bit complex to assess these things, which explains why we were struggling to come up with a number on Thursday evening during the class week.. But at this point, I am fairly confident that the spreadsheet does a reasonable job of assessing the benefit (or not) of using an energy wheel.

As you will see, in terms of saving energy, the installation at Muir actually spends more energy in the recovery process than it saves, even after we "fixed" it. This is the savings projection with 80% effectiveness, constant flow and a schedule.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	61,074,177	4,343		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	763	5,212		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$249	$419	$668	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	58	8.5		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	72	10.2		Note 14
Supply fan energy - kWh for both heating and cooling -	5,663			
Exhaust fan energy - kWh for both heating and cooling -	1,814			
Wheel motor - energy kWh for both heating and cooling -	4,476			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			11,952	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$961	
Net energy savings -			-$293	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	11,900,971	770		Note 16
Potential energy savings lost due to leakage, $ -	$39	$74	$113	
Hours of operation -			3,510	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.0%	73.0%	54.7%	(see Efficiency Equation tab)

But the fix did improve things. This is what it was (same assumptions as above) with a 40% effectiveness.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	29,094,392	2,069		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	364	2,483		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$119	$200	$318	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	27	4.0		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	34	4.8		Note 14
Supply fan energy - kWh for both heating and cooling -	5,663			
Exhaust fan energy - kWh for both heating and cooling -	1,814			
Wheel motor - energy kWh for both heating and cooling -	4,476			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			11,952	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$961	
Net energy savings -			-$643	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	5,950,485	385		Note 16
Potential energy savings lost due to leakage, $ -	$19	$37	$57	
Hours of operation -			3,510	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.0%	36.3%	27.0%	(see Efficiency Equation tab)

What that means is that for Muir, the justification for the Energy Recovery Unit (ERU) (in theory) would have been based on the reduction in first cost and demand charges associated with selecting equipment rather than energy savings. In other words, the benefit of the ERU assumed that the ERU would reduce the load that would need to be met on the design day and thus the tonnage and Mbh that would have to be purchased and the associated demand charge.

The spreadsheet numbers are probably conservative. Meaning, the current spreadsheet models a constant flow system, which Muir is not and varying the flow will lower the amount of energy needed and recovered.

But the spreadsheet does model scheduled operation and Muir was running 24/7 as I recall. So, if that situation persisted (24/7), then the numbers look more like this. Here is the result with the baffle missing, which we estimated made the heat wheel 40% effective.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	78,205,747	4,436		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	978	5,323		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$319	$428	$747	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	28	4.1		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	34	4.9		Note 14
Supply fan energy - kWh for both heating and cooling -	13,942			
Exhaust fan energy - kWh for both heating and cooling -	4,526			
Wheel motor - energy kWh for both heating and cooling -	11,169			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			29,637	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$2,383	
Net energy savings -			-$1,635	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	16,042,667	864		Note 16
Potential energy savings lost due to leakage, $ -	$52	$83	$136	
Hours of operation -			8,759	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.0%	36.3%	26.9%	(see Efficiency Equation tab)

And here is what it comes out like after we add the baffle, which we estimated made the heat wheel 80% effective.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	164,167,436	9,312		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	2,052	11,175		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$670	$898	$1,568	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	58	8.5		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	72	10.2		Note 14
Supply fan energy - kWh for both heating and cooling -	13,942			
Exhaust fan energy - kWh for both heating and cooling -	4,526			
Wheel motor - energy kWh for both heating and cooling -	11,169			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			29,637	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$2,383	
Net energy savings -			-$814	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	32,085,333	1,727		Note 16
Potential energy savings lost due to leakage, $ -	$105	$167	$271	
Hours of operation -			8,759	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.0%	73.0%	54.5%	(see Efficiency Equation tab)

So, not the thousands of dollars a year we had thought at the time, but hundreds of dollars a year, so still helpful.

Plus the loss of effectiveness could have been one of the reasons that the facility could not hold set point during extreme weather. In other words, if the designer took credit for the recovered energy at the rated effectiveness, they would have been short 8 or 9 tons on the design day, which means the chiller would have needed to be selected for an additional 10-12% of the rated capacity called out in the documents. So, we probably helped with that.

And, certainly the heat gain/loss in the exhaust duct comes into play if the designer did not anticipate it. The spreadsheet currently assumes 10 degrees on the extreme day and de-rates it as a function of indoor to outdoor temperature difference and then adjusts the wheel exhaust entering temperature to degrte the amount of energy that is recovered as a result. Here is what happens if I change that to 4°F.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	80,433,099	4,636		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	1,005	5,563		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$328	$447	$776	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	76	9.2		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	94	11.0		Note 14
Supply fan energy - kWh for both heating and cooling -	5,663			
Exhaust fan energy - kWh for both heating and cooling -	1,814			
Wheel motor - energy kWh for both heating and cooling -	4,476			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			11,952	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$961	
Net energy savings -			-$185	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	15,921,530	813		Note 16
Potential energy savings lost due to leakage, $ -	$52	$78	$130	
Hours of operation -			3,510	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.3%	73.5%	57.1%	(see Efficiency Equation tab)

I am not sure if the effectiveness numbers were a SWAG or an actual assessment from the data, but if they were a SWAG, I suspect we might have the data needed to firm them up.

Alarming as the numbers are in terms of energy savings delivered by the unit, I think my spreadsheet is a reasonable representation of things. I say that because most of the folks selling these things would say they are marginally beneficial in a lot of climates and operating scenarios, including the Ft. Leavenworth application given the flow rate and climate.

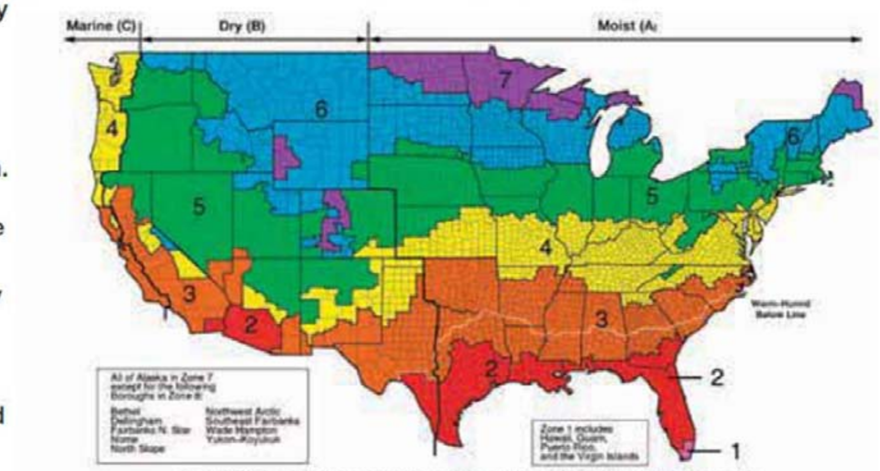
Here is what Greenheck says in their catalogue ...

Why use energy recovery?

A 100% outdoor air unit's primary responsibility is to dehumidify the incoming air, however, it inherently handles large heating and cooling loads in the process. The addition of energy recovery significantly reduces the size of the equipment required to sufficiently condition this air.

ASHRAE 90.1-2010 requires the use of energy recovery based upon a unit's supply airflow, outdoor air percentage, and geographic location. The standard mandates the total effectiveness (sensible and latent) be a minimum of 50% when required.

The effectiveness of energy recovery devices varies depending on the device type, material, and airflow balance. This value is determined based on the test procedure outlined in the Air-Conditioning, Heating, and Refrigeration Institution (AHRI) Standard 1060.



Climate zones (by county) for the 2004 Supplement to the IECC, the 2006 IECC, and ASHRAE 90.1-2004.

Zone	Percentage of Outdoor Air at Full Design Airflow Rate (cfm)					
	30% ≤ 40%	40% ≤ 50%	50% ≤ 60%	60% ≤ 70%	70% ≤ 80%	≥ 80%
	Design Supply Fan Airflow Rate (cfm)					
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	≥ 5,000	≥ 5,000
1B, 2B, 5C	NR	NR	≥ 26,000	≥ 12,000	≥ 5,000	≥ 4,000
6B	≥ 11,000	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,500	≥ 1,500
1A, 2A, 3A, 4A, 5A, 6A	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,000	≥ 1,000	≥ 0
7, 8	≥ 2,500	≥ 1,000	≥ 0	≥ 0	≥ 0	≥ 0

NR = Not recommended

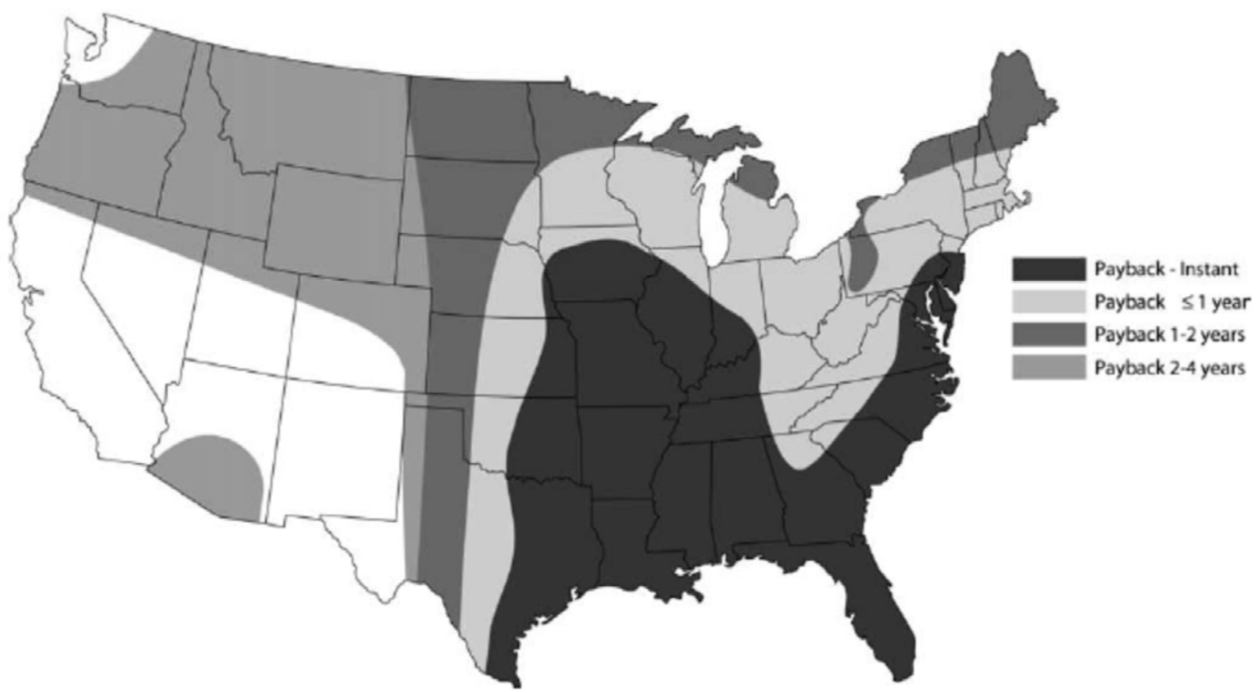
… and in their application manual.

UNDERSTANDING AND CALCULATING PAYBACK PERIODS

There are many choices that engineers have when considering possible solutions to providing adequate Indoor Air Quality. However, most alternatives are expensive. One of the attractive benefits of Greenheck energy recovery ventilators is that they are very economical. Low first cost and exceptional energy savings combine to provide payback periods of less than one year in many U.S. markets.

This chapter is a tool to understand how payback can be calculated. To obtain a general feel for the economics of Greenheck ERVs, a payback map is shown for the following assumptions:

- Office building with HVAC system operating 16 hrs/day, 5 days/week
- ERV installed cost of $3.60 per cfm
- Air Conditioning equipment installed cost of $1,000 per ton
- Energy costs of $0.06 per kW-h and $0.60 per Therm
- Energy recovery effectiveness of 75%



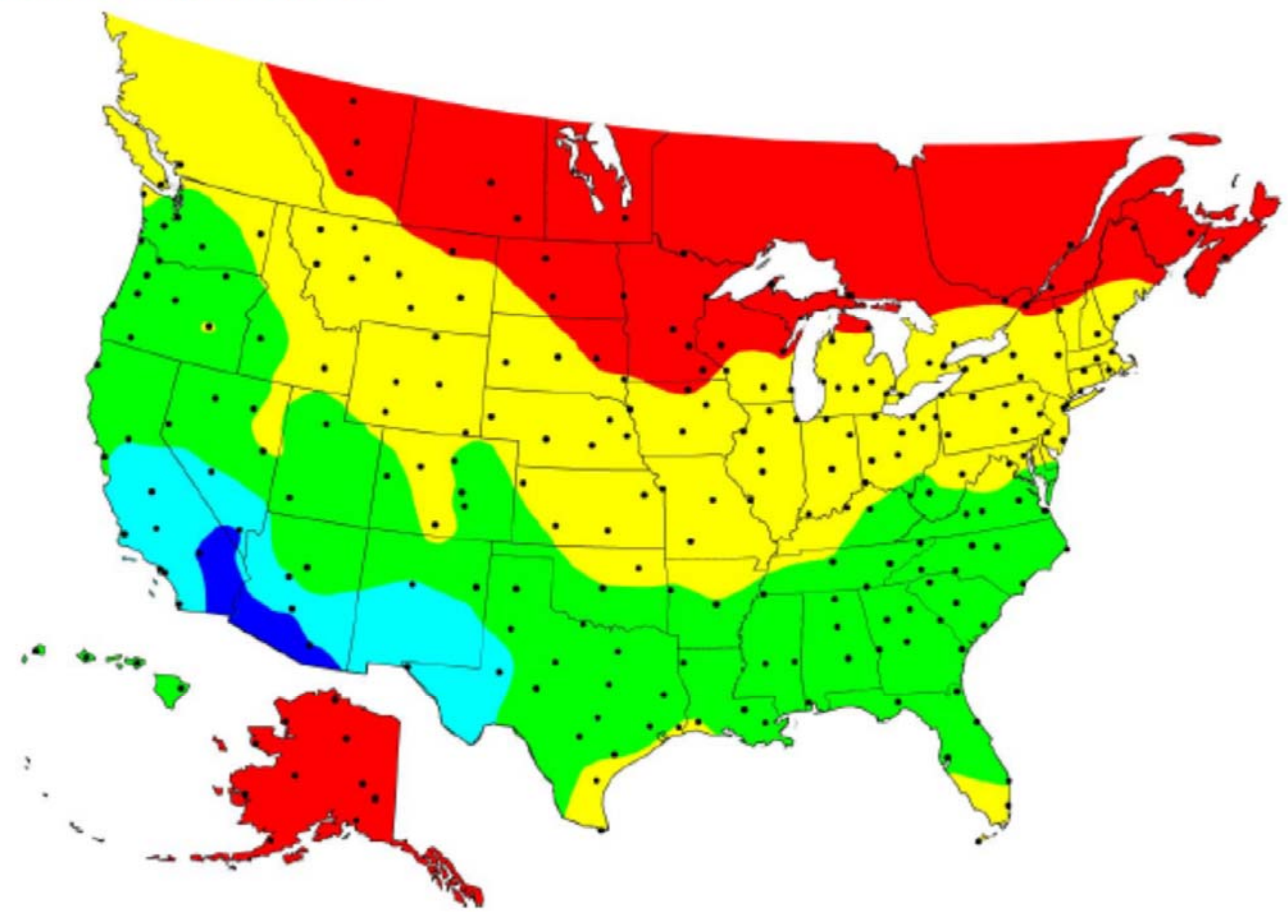
And here is what Loren Cook says.

ERV Annual Energy Savings

Ventilation rates prescribed by ASHRAE Standard 62 have required mechanical designers to significantly increase the amount of outdoor air provided to occupied spaces. The high efficiencies of energy recovery ventilators allow engineers to meet the ASHRAE 62 Standard and continue to design energy efficient structures. In the winter, heat and moisture recovered from the warm indoor exhaust air is transferred to the cold outdoor air being introduced into the building. With the heat transfer effectiveness as high as 85 percent, winter fuel bills can be drastically reduced while providing a healthy and comfortable indoor environment. Similar energy savings can be realized in the summer months as warm, humid outdoor air is cooled and dehumidified before it is introduced to the conditioned space, thus reducing air conditioning load.

The annual energy savings map illustrates how operating cost savings can be substantial. While energy savings are very good across the southern United States, they are excellent throughout the central and northern United States and all of Canada. Detailed analysis, including first cost and monthly heating and cooling savings for a specified application can be calculated using the Cook Compute-A-Fan selection software.

Annual Energy Savings Map



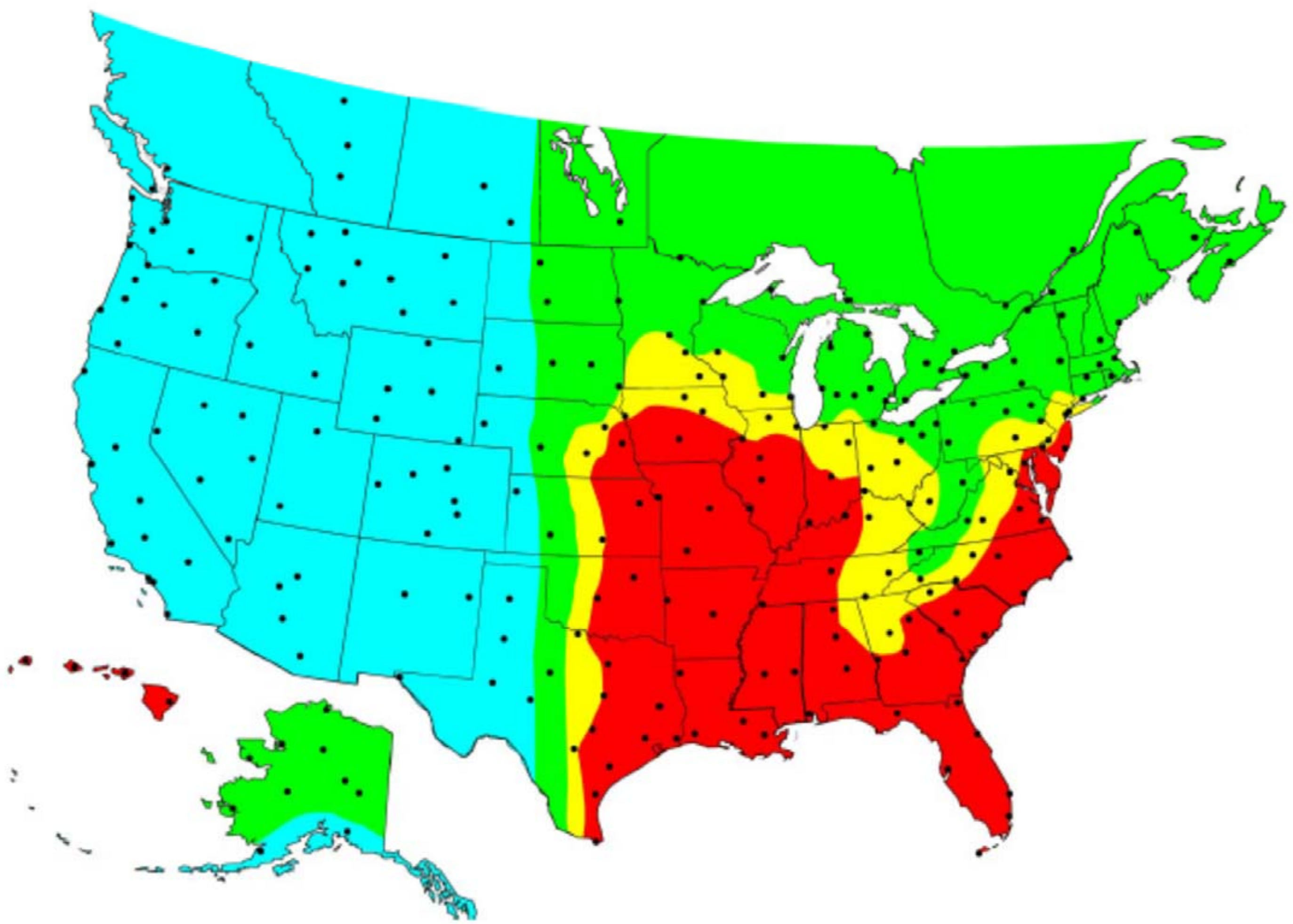
Operating Assumptions

This map illustrates typical annual energy savings (in dollars per 5,000 cfm) by location. The analysis is based on the following assumptions.

- Hours of operation: 6 a.m. to 10 p.m., five days per week
- Cooling source EER: 10.0
- Summer indoor design: 75°Dry Bulb, 50 percent Relative Humidity
- Electric cost: $.07/kwh
- Winter indoor design: 72°Dry Bulb, 35 percent Relative Humidity
- Heating source: Gas, $.60/therm.
- Wheel effectiveness: 75 percent latent and sensible
- Calculations include ERV operating costs

Savings per Year
$0-500
$501-1500
$1501-2500
$2501-3500
$3501 +

Payback Map



Operating Assumptions

This map illustrates the time required to recover the ERV equipment cost. The analysis is based on the following assumptions.

- Hours of operation: 6 a.m. to 10 p.m., five days per week
- Cooling source EER: 10.0
- Summer indoor design: 75˚Dry Bulb, 50 percent Relative Humidity
- Electric cost: $.07/kwh
- Winter indoor design: 72˚Dry Bulb, 35 percent Relative Humidity
- Heating source: Gas, $.60/therm.
- Wheel effectiveness: 75 percent latent and sensible
- ERV installed cost: $3/cfm
- A/C equipment installed cost: $1,000/ton
- Calculations include ERV operating costs

Payback Period in Years

- Instant
- Less than 1 year
- Less than 3 years
- More than 3 years

[David Sellers]

Here is where my spreadsheet lands if I make the assumptions match the assumptions Loren Cook cites in their maps.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	158,082,110	10,450		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	1,976	12,540		
Energy rate - $/therm or $ per kWh -	$0.60000	$0.07000		
Savings associated with recovered energy -	$1,186	$878	$2,063	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	126	18.1		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	157	21.7		Note 14
Supply fan energy - kWh for both heating and cooling -	6,149			
Exhaust fan energy - kWh for both heating and cooling -	2,656			
Wheel motor - energy kWh for both heating and cooling -	5,100			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			13,906	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$973	
Net energy savings -			$1,090	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	18,053,420	1,130		Note 16
Potential energy savings lost due to leakage, $ -	$108	$95	$203	
Hours of operation -			4,000	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.1%	71.9%	60.6%	(see Efficiency Equation tab)

I come up with the value of the recovered energy being $2,063, and the net savings when you take the fan and wheel motor energy into account being $1,090. For the Ft Leavenworth area, Loren-Cook projects savings of $2,501 (not $2,500) to $3,500 per year and that their calculations include the ERV operating costs. But they don't really go into if that means just the wheel motor (assumes you would have to move the air anyway) or if that includes both the supply and exhaust fans.

My number above includes supply and exhaust fan energy since the arrangement at Ft. Leavenworth was such that there was a separate AHU that moved the air to the zones, which is basically moving the air that is introduced by the DOAS system for the zones that don't have the dual connection VAV boxes. So the DOAS fan energy represents an additional burden that would not be there if you didn't do a DOAS system.

But, if you had an arrangement like I have on a lot of jobs up in Seattle, where the DOAS sends air to zones served by VRF fan coils, then even if you didn't have energy recovery, you would still have to move the air albeit with out the energy wheel pressure drop. If I eliminate the supply and exhaust fan energy from my calculation to sort of mimic that, then here is where I end up.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	158,082,110	10,450		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	1,976	12,540		
Energy rate - $/therm or $ per kWh -	$0.60000	$0.07000		
Savings associated with recovered energy -	$1,186	$878	$2,063	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	126	18.1		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	157	21.7		Note 14
Supply fan energy - kWh for both heating and cooling -	0			
Exhaust fan energy - kWh for both heating and cooling -	0			
Wheel motor - energy kWh for both heating and cooling -	5,100			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			5,100	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$357	
Net energy savings -			$1,706	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	18,053,420	1,130		Note 16
Potential energy savings lost due to leakage, $ -	$108	$95	$203	
Hours of operation -			4,000	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.3%	73.9%	67.3%	(see Efficiency Equation tab)

So, where that all left me in terms of believing my spreadsheet was that while I didn't have an exact match, I was coming up with numbers in the same general range vs. being an order of magnitude different (i.e. they say $2,500 per year and I come up with $250 or $25,000 per year). And, as you can see from the inputs tab, there are a lot of other decisions/assumptions that you need to make to do the math on this that are not called out in the manufacturer's assumptions.

So my bottom line on the spreadsheet is that it is a tool that would give a reasonable sense of what the potential order of magnitude are.

To me, one of the most significantly different things about the system we have at Muir (which I suspect is very similar in terms of cost to the one in Flint) and what the manufacturers are basing their payback assessment costs on is cost per cfm for one of these systems. Greenheck's assumption is an installed cost of $3.60 per cfm from a document copyrighted in 1997. Loren Cook's assumption is an installed cost of $3 per cfm from a document dated March 2016.

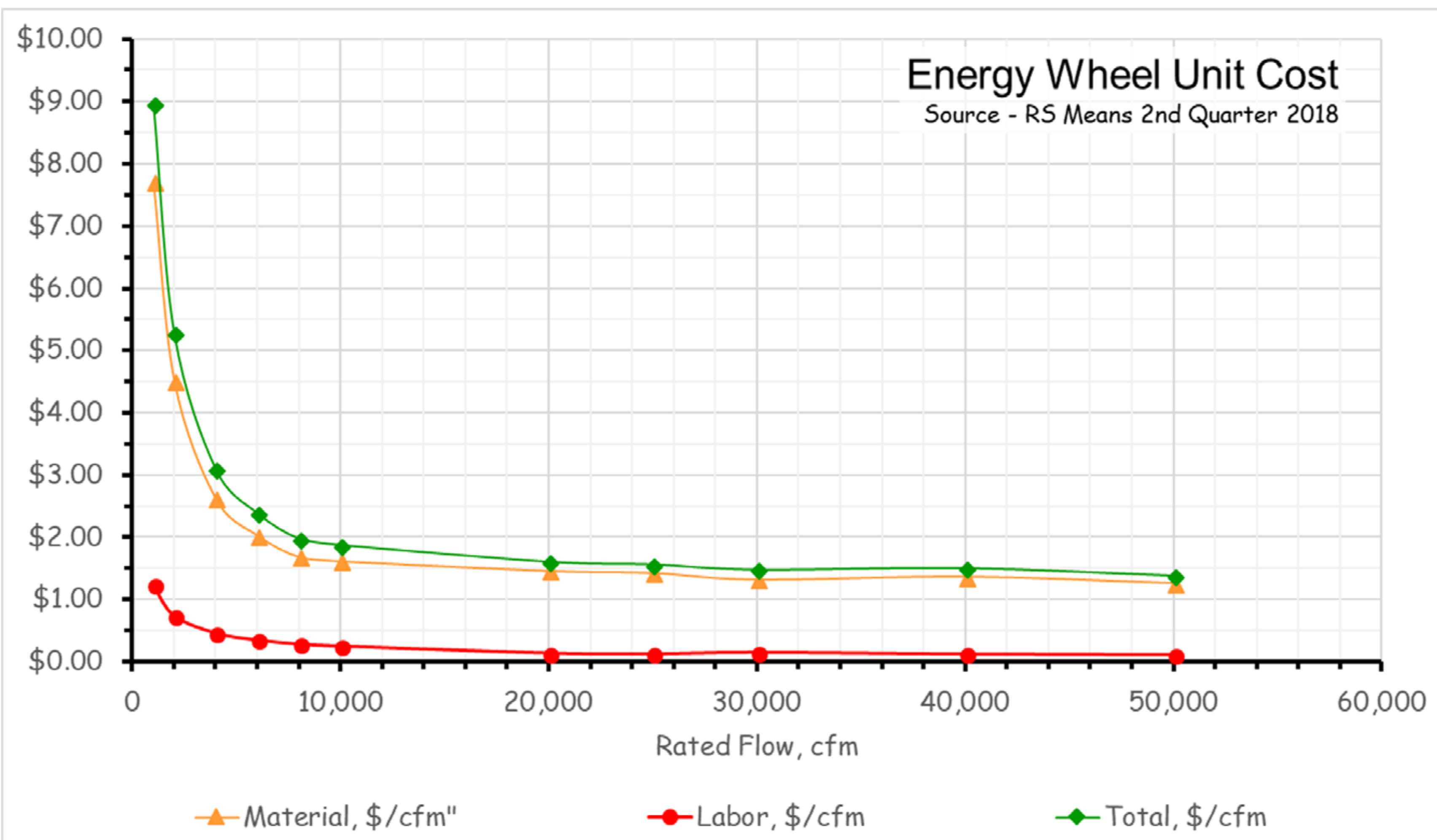
So, their numbers are the same order of magnitude from documents that have significantly different ages. But they are the current documents that you find on their web sites. So, I don't know if that means that the vendors have updated their number and simply not changed the copyright information or if the numbers are dated and should be adjusted for inflation.

If you use the Bureau of Labor Statistics Inflation Calculator …

https://www.bls.gov/data/inflation_calculator.htm

… to adjust the numbers, Greenheck's number becomes $5.69 per cfm installed and Loren Cook's becomes $3.18, installed (vendor definition of installed, which is not stated anyplace that I saw).

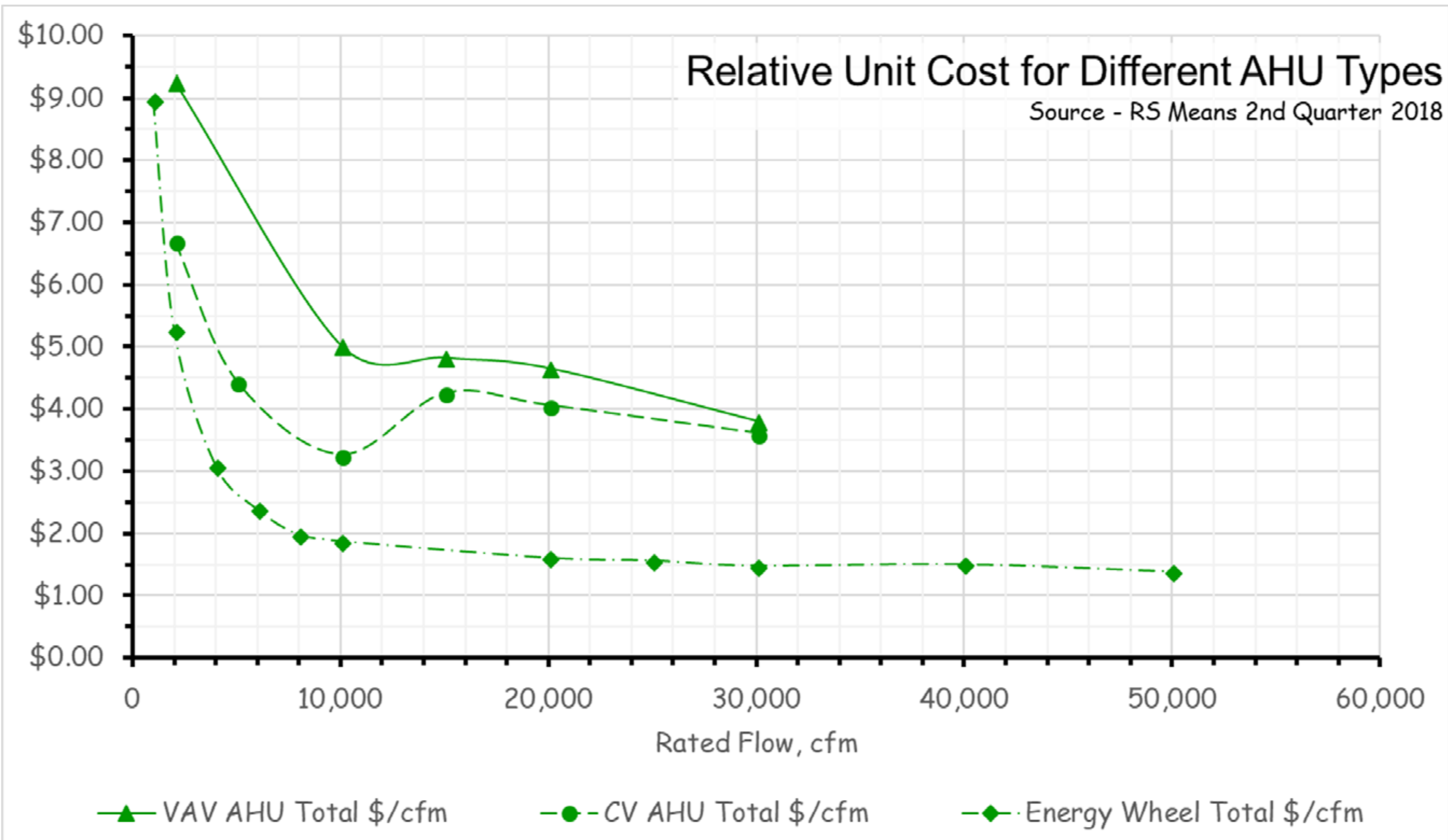
If you look at RS Means, here is where you end up.



If you interpolate that for 5,000 cfm, which is the approximate size Loren Cook and Greenheck seem to have targeted for their quote in their manuals, then you end up significantly lower than them; about $2.74. But at that point, you are also on a very volatile portion of the cost vs. cfm curve.

Plus, there are a ton of options you can purchase with one of these units, like controls, coils, bypass systems, isolation dampers, etc. So, I suspect the $ per cfm number is by nature, pretty volatile and a rule of thumb at the most (probably an optimistic rule of thumb designed to make you want to purchase a unit based on the energy savings it can deliver) (ideally, you will use the payback maps the vendors provide to make your decision).

Here is how the ERU compares to other AHUs based on RS Means data.



Also, in all cases, the term "installed cost" is subject to interpretation. For instance, I believe the RS means numbers include what it would take to get the unit sitting on it's pad and bolted down. But they would not include power, piping, and controls, and probably not the pad. Similar considerations might apply to Greenheck's and Loren-Cook's use of the term "installed cost"; they just don't say.

Early on in my career, I realized that you have to be really careful about that. The sales guys want to sell equipment so they are going to be optimistic. And you want to save energy, so you will "hear what you want to hear" and maybe forget to ask things like "so, does your installed cost include the piping and wiring and controls?".

But the real "attention grabber" comes if you look at the data you guys have that is specific to Muir/Flint …

FORT LEVENWORTH FLINT AND MUIR HALL

Mark: HRU-1 Model: ERCH-45H-15 Product Family: Energy Recovery

Qty	Supply FRPM	Outdoor Volume (CFM)	Supply SP (in wg)	Exhaust FRPM	Exhaust Volume (CFM)	External SP (in wg)	List
1	1,658	3,500	1.75	905	2,250	0.75	$47,841

ID: 4

Tag HRU-1

TAGS

SELECTION		CONFIGURATION		MOTOR SPECS	
Elevation (ft):	800	OA Intake Position:	Top	Outdoor Size (hp):	5
Weatherhood:	No	OA Discharge Position:	Top	Exhaust Size (hp):	1 1/2
Frost Controls:	Timed Exhaust	EA Intake Position:	Top	UL:	UL/cUL-1995
Night Setback:	No	EA Discharge Position:	Top	Enclosure:	ODP
Outdoor Damper:	Yes			Power:	60 Cycle
Outdoor Filters:	Pleated			Phase:	3
Exhaust Damper:	Yes			Voltage (V):	208
Exhaust Filters:	Pleated			RPM:	1725
				Efficiency Selected:	SE
				MCA (A):	29.2
				MOCP (A):	45.0

HEATING:
Hot Water - 1 Coil - Model: 5WQ0802B - 51 x 24 - Conn. Size- 2.5 - 12.5 GPM $4,226

COOLING:
Chilled Water - 1 Coil - Model: 5WQ1206C - 51 x 24 - Conn. Size- 2 - 29.1 GPM $9,561

ACCESSORIES:	
Outdoor Air Intake Damper, Motorized, Low Leakage VCD-23	$1,515
Exhaust Air Intake Damper, Motorized, Low Leakage VCD-23	$1,226
Duct Flange	$236
Outdoor Air Filter, 2" pleated (30% efficient)	$711
Exhaust Air Filters, 2" pleated (30% efficient)	$711
Listed to UL-1995	$31
Water Coil(s) piped external to unit	Incl.
Temp Control by Others	Incl.
Timed Exhaust Frost Control	$562
Variable Air Volume - Modulating	$4,830
Extended Subtotal ($)	$71,450
ER1 0.2440	17,433.80

… which says all of those numbers are way off relative to the rules of thumb in their literature, said rules of thumb making the economics look much more favorable than the will actually be if the motivator for doing this is to save energy.

Specifically, from the Muir data, for a 3,500 cfm unit (I think that was Muir), the basic ERU cost was $47,841 or $13.67/cfm. The unit that you actually bought, with the additional coils, was $71,450 or $20.41/cfm. So order of magnitude differences from the numbers in the Loren Cook an Greenheck "you really should do this" information.

That said, from an economics perspective, the other thing this approach gets you is lower first cost for the heating and cooling equipment (fewer tons/Mbh required because you recovered some of it), and a lower peak demand. Both of those things can be significant. For instance, with the unit running at 80% effectiveness (which could be a stretch but someone thought that was the design target as I recall) then for Muir, the peak capacity requirement was reduced by 8.5 tons and the peak electric demand was reduced by 10.2 kW. At a nominal $1,000 per ton for capacity (very general but it's the number Loren Cook is using), you saved $8,500 in chiller first cost thanks to the energy recovery unit. And at $16.2836 per kW with a ratchet (12 months I assume), you save $1,993 per year in demand charges.

But the down side is that if you de-rate the primary equipment in light of the recovered energy, you are counting on the unit to work and counting on it to work at the design effectiveness (unless you make an allowance for degradation over time).

So bottom line, there are other things to consider in terms of cost benefit besides the energy savings. But I suspect if you asked your "average Sue or Joe out on the street" they would have the perception that the ERU would pay for itself via energy savings in 1-3 years, maybe faster in Leavenworth, Kansas based on the manufacturer maps and charts. But from what I can tell, that would be highly unlikely, especially in the smaller unit sizes where the parasitic energy may exceed the energy savings you achieved in recovered energy (which appears to be potentially what is going on at Muir if my spreadsheet has any measure of validity.

From what I can tell, the energy recovery numbers are really sensitive to a number of things.

1. *Hours of operation; obviously, the more you run the thing, the more you recover. But also, the more you run the thing, the more parasitic energy that you spend. So larger units with more efficient fan selections and more efficient motors will come off better than smaller units simply because of lower parasitic losses. From what I can tell, you have multiple fan choices for these pieces of equipment when you select them, so even in a given unit size, there would be an opportunity to reduce the parasitic burden by making the most efficient fan selection.*

   But in a first cost driven environment, you will probably get the smallest, fastest spinning forward curved wheel that will provide the flow and static you need vs. a larger, slower spinning backward inclined or airfoil wheel. And I suspect that the manufacturer's case studies assume the most efficient fan selections to keep the parasitic losses down, but then sell the least efficient fan unless someone forces the issue by scheduling the fan efficiency or bhp.

2. *Variable flow; VAV systems save energy for sure, But if you are recovering energy, you will also recover less simply because you don't need as much as the design flow rate most of the time. So you end up with a bit of a paradox in that you have to put in something large enough for the design day (and pay for it) but one of the things that you are using to justify the installation (energy savings) is minimized (if everything works right) because most of the time you simply don't need and thus don't have to recover as much energy as you do on the design day.*

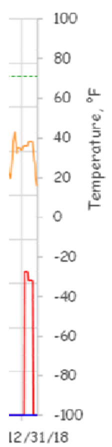
3. *Balanced flow; Having the supply flow and the exhaust flow the same improves the effectiveness.*

   Here is what happens when I make the exhaust flow in the Muir unit the same as the supply flow.

	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	104,355,090	7,385		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	1,304	8,863		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$426	$712	$1,138	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	98	14.2		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	123	17.1		Note 14
Supply fan energy - kWh for both heating and cooling -	5,663			
Exhaust fan energy - kWh for both heating and cooling -	2,821			
Wheel motor - energy kWh for both heating and cooling -	4,476			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			12,960	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$1,042	
Net energy savings -			$97	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	11,900,971	770		Note 16
Potential energy savings lost due to leakage, $ -	$39	$74	$113	
Hours of operation -			3,510	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.1%	75.3%	60.4%	(see Efficiency Equation tab)

   If you compare this the first table, you can see that in theory, balancing the flow changes things from a net savings that is a negative $293 per year (due to the parasitic energy of the fans and wheel motor) to a positive net savings of $97 per year.

4. *Flow rate; as the flow rate goes up, the fan efficiency improves (potentially, if you select the fan right) and the motor efficiency improves too, mostly because the motor gets bigger and larger motor's generally have better efficiency. And the $ per cfm costs drop, as we saw above. Here is what happens if I make the Muir unit 10 times larger (35,000 cfm) with balanced flow.*



	Heating	Cooling	TOTAL	
Total energy recovered, Btu for heating, Ton-hours for cooling -	1,043,550,902	73,854		
Boiler efficiency, % or chiller efficiency, kW/ton -	80%	1.20		
Energy saved - therms for heating, kWh for cooling -	13,044	88,625		
Energy rate - $/therm or $ per kWh -	$0.32655	$0.08039		
Savings associated with recovered energy -	$4,260	$7,125	$11,384	
Recovered energy - Peak Value - Mbh for heating, Tons for cooling -	985	142.2		Note 13
Potential demand reduction - Mbh for heating, kW for cooling -	1,231	170.7		Note 14
Supply fan energy - kWh for both heating and cooling -	33,084			
Exhaust fan energy - kWh for both heating and cooling -	16,108			
Wheel motor - energy kWh for both heating and cooling -	12,806			
Total additional energy cost to operate the wheel - kWh for both heating and cooling -			61,998	
Total additional energy cost to operate the wheel - $ for both heating and cooling -			$4,984	
Net energy savings -			$6,400	Note 17
Potential energy savings lost due to leakage, Btu for heating, Ton-hours for cooling -	119,009,707	7,695		Note 16
Potential energy savings lost due to leakage, $ -	$389	$742	$1,131	
Hours of operation -			3,510	
Minimum/Maximum/Average Recovery Efficiency (Should always be less than the nominal effectiveness of 80%) -	0.1%	77.7%	67.3%	(see Efficiency Equation tab)

You end up with a significant net savings ($6,400 per year) plus significant demand and peak capacity reduction, all of which can be used to justify a first cost of $52,500 (using the RS Means data for consistency) vs. $93 per year in energy savings plus some demand and peak capacity reduction which needs to justify a first cost of $12,250 using the RS Means numbers. And, in reality, the "tricked out" unit with the options specified by the design was way more expensive than that.

5. *Climate; In places like the Pacific Northwest, where humidity's are low and temperatures are mild, compared to just blowing outdoor air through the building, ERUs may not have much to offer when compared to a hot and humid environment like those in the South Eastern USA. Yet, the codes are being written in a way that mandates their use.*

Of course, I'm sure the people writing these things into mandatory code and standard requirements have thought about all of this. So, not to worry.

One of the things that was discussed over the course of the week, in particular on Thursday night (that I now have a better handle on) is the meaning of effectiveness vs. recovery efficiency.

A lot of that dialog occurred between Dwayne and I. Ultimately, I think the site Dwayne was referencing was calling what ASHRAE defines as effectiveness as the wheel efficiency. But the effectiveness (in the context of the ASHRAE definition) only looks at how much of the energy that was available was actually transferred. The efficiency includes not only the energy available to transfer in the denominator, but also the fan energy and wheel motor energy. By doing that, you can compare an energy wheel with, for instance an air to air energy exchanger (they exist) or a run around coil or any other technology for recovering energy and get a more realistic assessment.

The equations for effectiveness and recovery efficiency are in the spreadsheet, but here is a copy.

First effectiveness.

$$\varepsilon = \left(\frac{\text{Actual transfer of energy}}{\text{Maximum transfer of energy possible}} \right)$$

$$\varepsilon = \left(\frac{m_{Exh} \times \left(\eta_{Exh_{Lvg}} - \eta_{Exh_{Ent}} \right)}{m_{Min} \times \left(\eta_{Sup_{Ent}} - \eta_{Exh_{Ent}} \right)} \right) = \left(\frac{m_{Sup} \times \left(\eta_{Sup_{Ent}} - \eta_{Sup_{Lvg}} \right)}{m_{Min} \times \left(\eta_{Sup_{Ent}} - \eta_{Exh_{Ent}} \right)} \right)$$

Where:

ε = Wheel effectiveness
m_{Exh} = Exhaust mass flow rate
m_{Sup} = Supply mass flow rate
m_{Min} = Minimum of the two mass flow rates
$\eta_{Exh_{Lvg}}$ = Exhaust air leaving enthalpy
$\eta_{Exh_{Ent}}$ = Exhaust air entering enthalpy
$\eta_{Sup_{Ent}}$ = Supply air entering enthalpy
$\eta_{Sup_{Lvg}}$ = Supply air leaving enthalpy

The equations use the convention of viewing the energy transfer from the perspective of the exhaust air stream.

Thus, cooling the supply air is a numerically positive in terms of the energy change on the exhaust side because energy is added to the exhaust air stream and removed from the supply air stream.

Heating of the supply air is numerically negative from the perspective of the exhaust side, because energy is removed from the exhaust air stream and added to the supply air stream.

To maintain this convention and keep effectiveness a positive dimensionless number, under all operating conditions, the enthalpy terms in the numerator and denominator of the equations have been arranged so that if the numerator is positive (cooling supply air), then the denominator will also be positive.

Similarly, if the numerator is negative (heating of the supply air), then the denominator will also be negative due to the arrangement of the enthalpy terms.

This is purely to keep effectiveness a positive, dimensionless number. In a real system, physics will dictate that if energy is removed from one air stream, it will be added to the other and vice-versa and the equations follow this physical reality when you work with them.

In terms of data validation, if you are using logged data with these equations, effectiveness should always be positive. And the change in enthalpy on both sides of the wheel should be equal other than for any losses associated with leakage into or out of the AHU casing and

And now, recovery efficiency.

$$Eff_{EnergyWheel} = \frac{Q_{Recovered}}{Q_{Input}}$$

$$= \frac{Q_{Recovered}}{\left(Q_{Recovered_{MaxPossible}} + W_{SupplyFan} + W_{ExhaustFan} + W_{WheelMotor}\right)}$$

$$= \frac{m_{Sup} \times \left(\eta_{Sup_{Ent}} - \eta_{Sup_{Lvg}}\right)}{\left(\left[m_{Min} \times \left(\eta_{Sup_{Ent}} - \eta_{Exh_{Ent}}\right)\right] + W_{SupplyFan} + W_{ExhaustFan} + W_{WheelMotor}\right)}$$

Where:

$Eff_{EnergyWheel}$ = Energy wheel recovery efficiency
m_{Sup} = Supply mass flow rate, lb/hr
$\eta_{Sup_{Ent}}$ = Supply air entering enthalpy, Btu/lb
$\eta_{Sup_{Lvg}}$ = Supply air leaving enthalpy, Btu/lb
m_{Min} = Minimum of the two mass flow rates associated with the wheel (m_{Sup} and m_{Exh})
m_{Exh} = Exhaust mass flow rate, lb/hr
$\eta_{Exh_{Ent}}$ = Exhaust air entering enthalpy, Btu/lb
$W_{SupplyFan}$ = Supply fan energy, Btu/hr
$W_{ExhaustFan}$ = Exhaust fan energy, Btu/hr
$W_{WheelMotor}$ = Wheel motor energy, Btu/hr

Note that if the enery recovery unit includes auxilliary heat transfer elements provided to supplement the recovered energy, then the fan power should be adjusted to eliminate the static pressure loss associated with them from the efficiency assessment since those elements would be required with our with out the energy recovery wheel.

If independent filters are provided for the energy recovery wheel, then the static loss associated with them should be included in the fan energy since they would not be there if the wheel was not there.

The spreadsheets are quasi-user friendly at this point. But there are quite a few variables that need to be addressed and input. I have included notes about the critical items but have not made an "Instructions" tab yet. But the idea was to get something together that would allow you to use it in a number of ways. Right now, I have it populated with TMY file data and do the calculation for a year that way. The spreadsheet also uses the rated performance data for the unit. But, you can improve the result by adjusting those metrics based on logger data

For instance:

- ***What is the actual measured effectiveness?***

- *What does the flow profile look like?*
- *What are the actual motor sizes/efficiencies?*

Since the calculations in a row are just copied and pasted into the other 8,760 rows, you could just as easily paste them into a bin data file or into a logger data file. In the latter case, you would have to adjust the results based on the logger interval. With the TMY file, each row is an hour so the kW that comes out of it is also the kWh. Not so true for a logger sampling once every 15 minutes or something like that.

A quick overview of the tabs is as follows:

- *Inputs – Most of the inputs show up here although there are a few locations on the Calculation tab where you have to make some inputs. Generally, I have tried to highlight the cells that need to be input or adapted to the specifics of a project and have included notes to try to explain what is going on.*
- *Calculations – This is where all the math is done. It also includes a graph of the results for the entire year, mostly as a fast, visual sanity check. For instance, if you see, for instance a blue line (cooling energy recovered) and a red line (heating energy recovered) on top of each other, something is wrong someplace; its either one or the other. The summary of the results (the tables I kept pasting in above) are at the far right, top of the calculation tab.*
- *Enlarged Chart – This is the same graph as on the Calculations tab but pulled out as a normal "chart" with the axis compressed to a week (or a month or a day; whatever you make it).*
- *Max Possible – This is linked to the date and time and weather data in the Calculation tab. It lets you put in a few simple metrics (supply flow, exhaust flow, nominal indoor condition, effectiveness equipment efficiencies, and utility rates) along with the TMY file in the calculations tab to come up with the maximum potential energy that could be recovered, given the climate data along with what you could expect at the effectiveness value you entered. The calculation assumes a perfect world, 24/7 operation, and no parasitic energy or leakage across the wheel. The whole idea is to give you a quick perspective on your prospects right up front before you got down the road to far.*

  For example, for the Fort Leavenworth location once you pasted the TMY data into the Calculations tab, you can pretty quickly see that if you could recover everything from a unit that had 3,500 cfm of supply flow, 2,250 cfm of exhaust flow a nominal 71°F/50% indoor condition and 80% effectiveness, then you could save $2,806 a year in a perfect world (which it is not).

  So, if the vendor is saying the unit will cost $3.60 per cfm (which we now know could be wildly wrong) then the cost of the installed unit (with an uncertain definition of what "installed" means) would cost 3,500 cfm x $3.60 per cfm = $12,600. The simple payback on just energy savings (which is often how this stuff is marketed) would be $12,600/$2,860 per year = 4.41 years.

  This is slightly different from the less than one year to instant payback you get from the Greenheck and Loren-Cook maps. Plus you will never get there because of leakage and parasitic energy. Granted, you will reduce demand, and you could reduce the size of the equipment you purchased. But there is a risk associated with the latter if the wheel is off line for some reason or the performance degrades (say, for instance, someone forgets to install a baffle or something like that).

  And either way, for me at least, I would be feeling a lot more cautious about what I was going to do compared to how I would feel if I had just looked at the map and seen that in Leavenworth Kansas, the payback on one of these things is less than a year, maybe instantaneous. Knowing that once I added the features I needed to the unit, it might cost in the range of $48,000 - $71,000, not $12,600 would also give me pause.

  Just saying; this tab plus a bit of the other information in this e-mail gives you some perspective on where you are heading based on the realities of your site and what the equipment really costs.

- *Effectiveness Equation and Efficiency Equation – These tabs simply hold the equations I included above for reference.*
- *Air Density Equations – This tab is referenced by the calculations tab because it needs to use mass flow rate (vs. cfm) and these are the equations it uses to come up with that, provided for reference.*
- *Schedule and Occupancy – This tab lets you set up a schedule. And you can also use the occupancy data to drive a flow profile. I have not done that yet, but it is a feature that is available.*

- ***Holiday List* – *This lets you set up the holidays for a location. It is set to the federal holidays currently, but you can add your own, like Cloud Appreciation Day and stuff like that. If you want 24/7 operation, you clear out every thing but one holiday and then put in a date that is in a year that is not the year you are using with the TMY file.***

- ***Lines – This tab has the data that draws lines on the charts. The basic spreadsheet only has one line, but you can add others.***

- ***Title 24 Motor Eff. – This gives you a reference to use to pick a motor efficiency for the calculations tab where it requires one. If you pick the motor efficiency associated with a motor that is one size larger than the bhp that comes up on the Inputs tab based on your flows and static pressures, then that should be a reasonable assumption.***

- ***Time Values – This is a utility tab that helps you set the axis parameters for the chart on the Enlarged Chart tab.***

Senior Engineer
Facility Dynamics Engineering
Northwest Satellite Office
8560 North Buchanan Avenue
Portland, Oregon 97203
Office - 503-286-1494
Cell - 503-320-2630
DSellers@FacilityDynamics.com
http://www.facilitydynamics.com/
Visit my Commissioning Resources website at www.Av8rDAS.com
View *A Field Perspective On Engineering* and past posts from
A Field Guide for Engineers at http://av8rdas.wordpress.com/
View *The Other Side of Life* at https://av8rdaslife.wordpress.com/