ENERGY RECOVERY VENTILATION

UNDERSTANDING
ENERGY WHEELS AND
ENERGY RECOVERY VENTILATION TECHNOLOGY

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INTRODUCTION

Application of air-to-air energy recovery equipment continues to grow in acceptance and use in HVAC systems. Increased outdoor air requirements necessary to meet ASHRAE Standard 62-1989 (1999), *Ventilation for Acceptable Indoor Air Quality*, and state and local building codes, add substantially to cooling and heating loads. Increasing outdoor air loads escalates both operating cost and system equipment cost. This has intensified interest in energy recovery technologies and their economic applications.

Energy recovery can be used for both new and retrofit applications. There are three categories of application: (1) process-to-process, (2) process-to-comfort, and (3) comfort-to-comfort.

In process-to-process applications, only sensible heat is captured from the process exhaust stream and transferred to the process supply stream. Exhaust temperature may be as high as 1,500°F.

In most process-to-comfort applications, energy recovery involves the capture and transfer of sensible heat only. Waste heat is transferred to makeup or outdoor air streams. This is effective during winter months, but requires modulation during spring and autumn to prevent overheating the building. Often, no energy recovery is made during summer.

Comfort-to-comfort applications differ from other categories in that both sensible and latent heat are often transferred. The energy recovery device transfers sensible heat from the warmer air stream to the cooler air stream. It also transfers moisture from the air stream with the higher humidity ratio to the air stream with the lower humidity ratio. The directions of humidity and heat transfer are not necessarily the same.

This white paper discusses air-to-air, comfort-to-comfort applications. Equipment and systems used for energy recovery ventilation are reviewed with particular emphasis given to rotary energy wheels that transfer both heat and moisture.

ENERGY RECOVERY APPLICATIONS

There are two basic seasonal scenarios for air-to-air energy recovery ventilation in comfort applications. The first is to transfer heat and moisture from the exhaust stream to the supply stream during winter months. The second is the reverse function: to transfer heat and moisture from the supply stream to the exhaust stream in the summer.

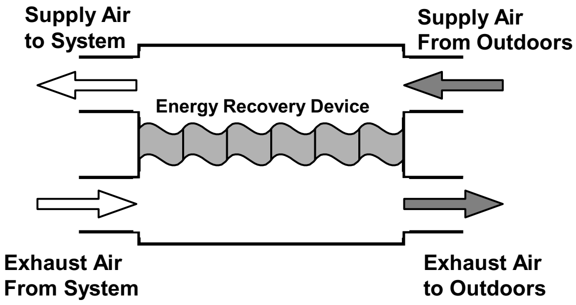


Figure 1. Counter-flow Heat Exchange Pattern

There are many possible applications of air-to-air energy recovery ventilation. Any building with comfort conditioning and relatively high levels of outdoor air, especially where latent cooling is a significant portion of the outdoor air requirement, is a likely candidate. Usually, buildings with significant occupancy levels that vary with the time of day are good candidates. For a typical office building, occupancy variability may be high between 8 a.m. and 5 p.m. and low other hours. Usually, these types of buildings must also conform to ASHRAE *Standard* 62. Typical applications may include:

- Schools (K-12) and universities
- Gymnasiums
- Office buildings
- Hospitals
- Nursing homes
- Correctional facilities
- Retail shopping centers

Some applications have severe requirements and great care must be taken to prevent cross-contamination between air streams. For instance:

- Laboratory fume hood exhaust
- Industrial applications with fumes or smoke (e.g., welding operations)
- Industrial applications with toxic or noxious exhaust
- Restaurants or kitchens
- Specialized hospital treatment areas

In these situations, the air streams must be physically isolated to insure there is no cross-contamination. This limits options for energy recovery to sensible heat transfer only.

ENERGY RECOVERY EQUIPMENT

Energy wheels that transfer both sensible and latent heat are the primary subject of this white paper. But, in the interest of understanding the benefits of energy wheels, it is useful to understand other technologies. The first thing to understand is that not all technologies are appropriate for every application. Each has benefits and limitations, and may be better suited to certain applications over others. For instance, energy wheels, as they are described in this paper, are ideally suited to comfort-to-comfort ventilation applications. A runaround loop can be similarly effective in transferring sensible heat, but it is much more complex and costly to use. On the other hand, a runaround loop can be applied successfully to harsh process applications where an energy wheel would fail. Table 1, at the end of this white paper, summarizes energy recovery equipment characteristics, advantages and limitations.

Energy Wheels

Energy recovery wheels are also called *heat wheels* and *enthalpy wheels*. Although many people use the phrases interchangeably, the term heat wheel is sometimes used to distinguish a sensible only application. Enthalpy wheel is used to distinguish a combined sensible and latent energy transfer application. In both cases, the fundamental piece of equipment is nearly identical. This discussion will use the term energy wheel as an all-inclusive class of rotary, air-to-air energy exchangers.

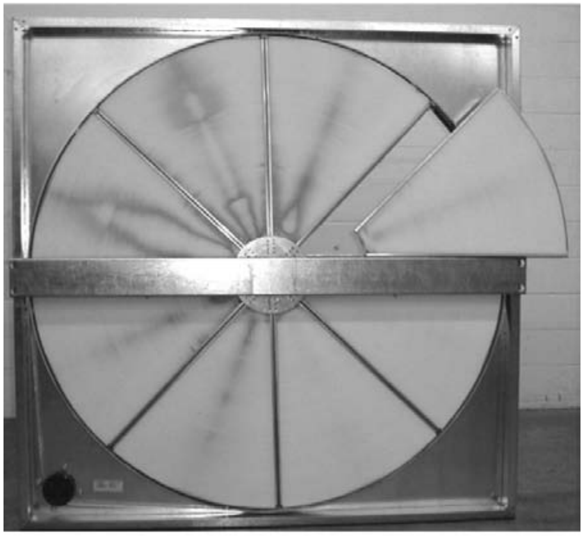


Figure 2. Rotary Energy Wheel.
Photo courtesy of Airxchange, Inc.

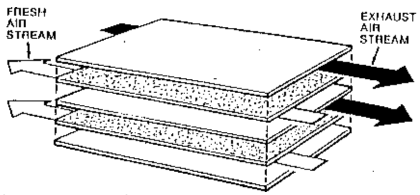
A rotary air-to-air energy exchanger has a revolving wheel filled with an air-permeable medium having a large internal surface area. The exchanger is designed to be positioned between two adjacent ducts with opposing flow directions. This establishes a counter-flow heat exchange pattern similar to that represented in Figure 1. The wheel rotates between 10 and 60 revolutions per minute depending on the application. When the wheel passes through the high-temperature air stream, the media temperature increases as heat is transferred and stored in the individual filaments. When the media wheel rotates into the low-temperature air stream, the filaments are cooled and release heat. This form of heat transfer is purely sensible and is driven by a temperature gradient between the high- and low-temperature air streams. In most comfort-to-comfort applications, the temperature difference is relatively small as compared to some process energy recovery applications.

Latent heat transfer can occur in one of two ways. First, if the temperature and humidity gradients are sufficient, water may condense on the cold media in the high-humidity air stream. Moisture droplets held in the media are carried to the low-humidity air stream where they evaporate. The second and more reliable means of moisture transfer happens when the heat transfer media in the rotary wheel is coated with a desiccant film. In the high-humidity air stream, desiccant material *adsorbs* moisture molecules by the process of vapor diffusion. The molecules ride the rotating wheel and are released (desorbed) into the low-humidity air stream. Although the overall process is considered energy transfer, the moisture adsorption-desorption process described is actually a mass transfer event. It is driven by the water vapor partial-pressure gradient between the high-humidity and low-humidity air streams. It is not dependent on the temperature gradient driving sensible heat transfer. This means that heat transfer can flow in one direction and moisture transfer can occur in the opposite direction because they are driven by different mechanisms.

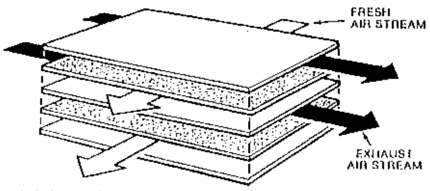
Fixed-Plate Heat Exchangers

The heat transfer core of fixed-plate heat exchangers is made from alternate layers of plates, formed and sealed at the edges to create two adjacent but separate airflow paths. Their most distinct advantage is that they have no moving parts. Energy transfer across the plates from one air stream to the next is completely passive and driven by the thermal gradient. Fixed plate heat exchangers are generally useful for sensible heat transfer only. Latent heat transfer can occur only if the plates are made from water vapor-permeable material.

Cross-flow is the most common arrangement. Counter-flow and parallel-flow exchangers have design and manufacturing complications that restrict their use. Units are available in many different materials, sizes and patterns, and are often modular, allowing combinations to fit large airflow applications. Plates are commonly spaced between 0.10 and 0.50 inches apart. Aluminum is the most commonly used material although plastics have been used without substantially affecting heat transfer efficiency. Although rare, fixed-plate heat exchangers can be constructed with water vapor-permeable materials such as treated paper or microporous polymeric membranes. The permeability of these materials enables a fixed-plate heat exchanger to transfer both sensible and latent heat.



COUNTER-FLOW ARRANGEMENT



CROSS-FLOW ARRANGEMENT

Figure 3.

Air streams are separated by folding, gluing or welding the plate edges and forming separate air paths. Spacing of the air paths is accomplished by molding integral dimples or ribbed patterns into the plates, or with external separators. Fixed-plate heat exchangers can be manufactured so there is little or no leakage between the air streams. Most units are constructed with drains for removing condensate and wash water.

Heat Pipe Heat Exchangers

Heat pipe heat exchangers have the appearance of ordinary finned coils, but each successive tube is independent and not connected to other tubes. Each tube is built with an internal capillary wick material. The tube is evacuated, filled with a Class I refrigerant and individually sealed. With the tubes installed horizontally, one half of the heat exchanger will act like an evaporator and the other half acts like a condenser. The high-temperature air stream passes through the evaporator half of the unit and the low-temperature air stream passes through the condenser half.

The high-temperature air stream passes over one-half of all the tubes. As the working fluid (refrigerant) is warmed and vaporized in the evaporator half, the internal vapor pressure gradient drives the gas to the condenser end of the tube. In the condenser end, the fluid releases the latent energy of vaporization as it condenses, thereby warming the low-temperature air stream. Liquid refrigerant returns to the evaporator end through the internal wick.

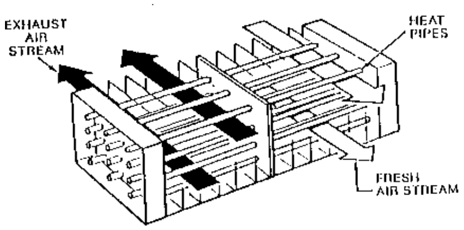


Figure 4. Heat Pipe Heat Exchanger

Heat pipes are usually constructed of copper tubes with aluminum fins. Tubes are installed horizontally, but tilting the tubes one direction or the other can control the amount of heat transfer. For instance, operating the heat pipe unit with the evaporator end lower than the condenser end improves the liquid refrigerant flow back to the evaporator and increases heat transfer capacity. Reversing the arrangement retards liquid refrigerant flow and decreases capacity.

Heat pipes are useful for sensible heat transfer only. Some latent benefit is achieved if the hot, humid outdoor air stream is cooled sufficiently to condense moisture on the evaporator end of the unit. Heat pipes can be installed so that cross-contamination between the two air streams is near zero.

Thermosiphon Heat Exchangers

Thermosiphon heat exchanger systems are similar in operation to heat pipes. They can operate as a single coil with sealed tubes, or function with separate evaporator and condenser coils as shown in Figure 5. The example shown in Figure 5 will transfer heat in either direction because the coils are installed at the same elevation. If the coils are installed at different elevations, the lower coil must always be the evaporator (high-temperature air stream).

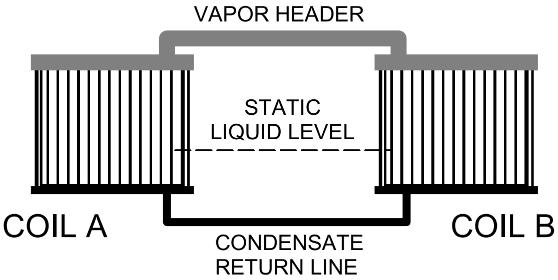


Figure 5. A bi-directional thermosiphon loop heat exchanger. With the coils installed at the same elevation, energy can be transferred in either direction.

Like heat pipes, thermosiphon heat exchangers are capable of sensible heat transfer only. But, they differ from heat pipes in two ways: (1) there is no wick to assist refrigerant flow so the piping must be designed for gravity return of liquid refrigerant; and (2) they depend on boiling for refrigerant vaporization which requires a larger temperature difference than is necessary for heat pipes. Circulating pumps and external sources of power are not required for operation.

Coil Energy Recovery Loops

Often referred to as a *runaround loop*, a coil energy recovery loop is actually a heat recovery *system* and distinct from individual pieces of equipment like energy wheels or fixed-plate heat exchangers.

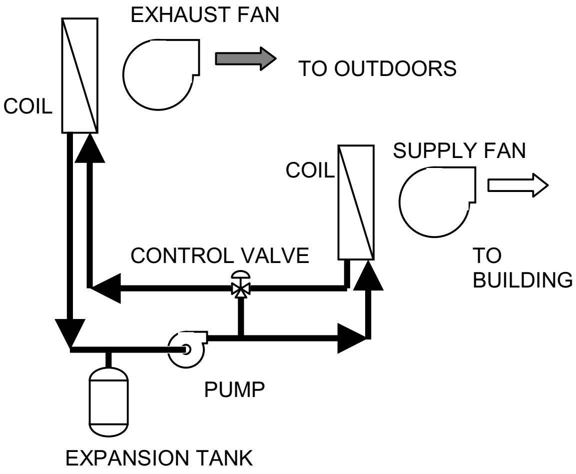


Figure 6. Runaround Loop

Coil energy recovery loops are very flexible and well suited to industrial applications or comfort-to-comfort applications with remote supply and exhaust ductwork. They use standard finned-tube coils to transfer heat to and from an intermediate working fluid such as water or glycol-water solution. A pump circulates the fluid between the two coils in closed loop. The loop must be equipped with a flow control valve to modulate the heat transfer rate. Also, an expansion tank is necessary for thermal expansion and pressurization of the working fluid.

The heat transfer rate must be controlled to prevent overheating or overcooling the supply air stream. If the outdoor air stream is very cold, an uncontrolled system may frost or freeze condensate on the coil in the exhaust stream. By regulating the fluid flow through each coil and blending warm fluid with the cold fluid entering the exhaust coil, the total heat transfer rate is limited to the maximum possible without freezing. Overheating is prevented in the same manner.

Runaround loops are well suited for applications that must keep the two air streams separate. They are useful for sensible heat recovery only, but they can be designed to transfer heat in either direction. They are also uniquely capable of simultaneous heat transfer between multiple locations using the same circulating system. Maintenance requirements are greater because there are more component parts than with passive energy transfer equipment. The system also requires electrical power, motor controls and temperature controls.

ENERGY WHEELS

Construction

Energy wheel design is generally similar between manufacturers. Units consist of a rotating wheel mounted on a sheet metal panel that is attached to two parallel ducts (or equipment housings with two adjacent air streams). Specific design and assembly features will vary somewhat. The descriptions below are typical and not to be construed as universal in the industry.

Energy recovery wheels are constructed with a circular, welded frame of anodized aluminum or stainless steel that holds the energy transfer media. The frame is constructed with a center hub and spokes that attach to a perimeter rim. The rim is a continuous, rolled stainless steel band that acts as a drive component. A large, flexible drive belt encircles the wheel rim and is driven by a small electric motor (about 1/2 hp). The media-wheel is supported in a flat, rectangular, sheet metal housing and rotates on a shaft held by two lubricated bearings.

The media wheel rotates between two adjacent air streams. To minimize leakage between the ducts, seals are installed at the wheel perimeter and at the duct penetration. Leakage is a result of two factors: (1) differential pressure between the ducts; and (2) air entrained in the media is exchanged between the two air streams as the wheel rotates.

Energy Transfer Media

The fundamental construction of the media is similar for both sensible-only units, and combined sensible and latent units. There are two fundamental types of media: random flow media and directionally oriented media.

Random flow media is made with sheets of woven wire or corrugated mesh. Multiple discs of media are assembled in layers (like pancakes), with each successive layer rotated slightly from the previous layer. This creates a random, turbulent air path through the media that encourages heat transfer. In large wheels, the media is partitioned into pie-shaped segments for easier handling. Random flow media requires a significantly larger face area than directionally oriented media for a given airflow rate and pressure drop.

Directionally oriented media is manufactured in several different configurations, all with small linear air passages that are aligned parallel to the flow direction. Air passages are similar in performance regardless of their shape. Media material can be plastic, aluminum or other metals, paper, or other synthetic material depending on the application.

One style of directionally oriented media consists of concentric filament bands of lightweight polymer plastic that are held in position by the wheel frame. Hundreds of filaments are layered to form the circular shape of the wheel (much the same way a tape measure is wound upon itself into a wheel shape). Each layer is separated from the adjacent layers by small dimples that are stamped into the flat side of the filament. The dimples space each layer uniformly, creating narrow channels for air to pass through. There are about 45 filament layers per inch of media wheel radius.

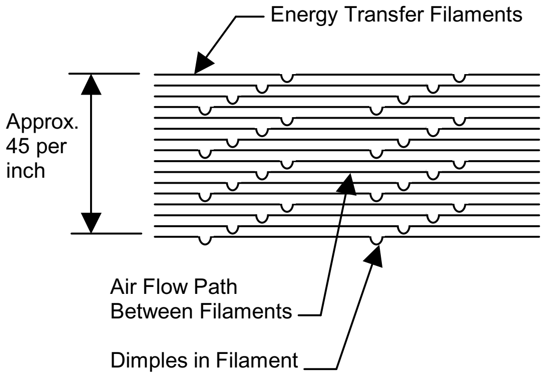


Figure 7. Section through energy transfer media (looking in direction of air flow)

When an energy wheel is to be used for both sensible and latent heat transfer, a desiccant coating is permanently bonded to the filament material. Several types of desiccant are available: zeolites, silica gel, molecular sieves, activated alumina, titanium silicate, lithium chloride and aluminum oxide. Zeolites, silica gel and molecular sieves are the most commonly used materials.

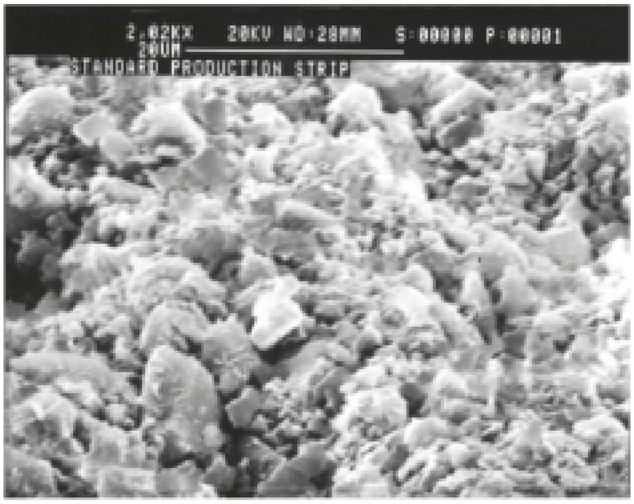


Figure 8. Scanning electron microscopic image of silica gel bonded to a polymer filament. Photo courtesy of Airxchange, Inc.

Although different desiccants have different adsorption characteristics, performance is not the most important differentiator. The most adsorbent desiccant, silica gel, will adsorb about 35 to 40% of its own weight depending on the relative humidity of the air stream. Molecular sieves and *granular* alumina are limited to about 20% adsorption. *Spherical* alumina will adsorb approximately 30 to 35%. The important focus is a desiccant's ability to remain reliably attached to the filaments' bands. Second, the desiccant cannot be adversely affected by periodic cleaning. All desiccants experience a decrease in their adsorption ability when dirty.

Units with an energy wheel greater than 25 to 30 inches in diameter should be manufactured with segmented wheels (see Figure 2). Segmented wheels are easier to handle and clean.

Energy Wheel Performance

Sensible heat transfer effectiveness is typically in the range of 50 to 80%. Total energy transfer performance, combining sensible and latent heat, is typically in the range of 55 to 85%.

Two examples at two different locations are provided below. Both examples have 2,200 cfm peak outdoor air requirement and 2,000 cfm exhaust, using an energy wheel with combined latent and sensible heat transfer. Energy savings are calculated using dry-bulb temperatures with mean coincident wet-bulb temperatures, and bin and degree hour weather data published by ASHRAE.

Certain conditions are assumed to be common to both examples to simplify comparison:

- Building schedule: 12 months, 6 days/week, and 12 hr/day
- Electric rates: $0.05/kWh and $7.50/kW demand
- Cooling system EER: 10.5
- Heating system efficiency: 78%
- Fuel cost: $5.00/mmBtu

Example 1

Location: Tampa, Florida

Summer Conditions:
Indoor air: 75°F, 50% RH
Maximum outdoor air: 91°Fdb, 79°Fwb
Supply air from wheel: 78.3°Fdb, 66.8°Fwb

Summer Ventilation Load:
Sensible: 38,016 Btuh
Total: 138,258 Btuh
Recovered energy: 109,475 Btuh (9.12 tons)

Winter Conditions:
Indoor air: 72°F, 40% RH
Minimum outdoor air: 40°Fdb, 38°Fwb
Supply air from wheel: 65.3°Fdb, 53.6°Fwb

Winter Ventilation Load:
Sensible: 76,032 Btuh
Total: 99,577 Btuh
Recovered energy: 78,847 Btuh

Overall Effectiveness: 76.4 to 79.2%

Net Annual Operating Savings: $1,118

Example 1 - Bin Energy Analysis Summary

Outdoor Air °Fwb	MCWB °Fwb	Annual Hours	Vent. Load MBtu	Recov. Load MBtu
97.5	72.0	1	60	48
92.5	76.39	162	18,124	14,356
87.5	75.1	725	72,559	57,473
82.5	72.59	753	58,443	46,292
77.5	68.44	675	28,742	22,766
72.5	63.93	507	0	0
67.5	60.18	404	-219	-173
62.5	55.64	248	-1,971	-1,561
57.5	50.36	139	-5,353	-4,240
52.5	46.0	87	-5,390	-4,269
47.5	39.68	34	-3,154	-2,498
42.5	36.0	13	-1,390	-1,101
37.5	32.4	4	-528	-418
32.5	27.67	3	-365	-289
TOTAL				
Cooling		2,293	177,928	140,934
Heating		445	18,371	14,551

Example 1 – Annual Economic Summary

Supply Air, cfm	2,200		
Exhaust Air, cfm	2,000		
Air-Cond. Load Saved, MBtu		140,934	
Air-Cond. Operating Savings			$1,076
Heating Load Saved, MBtu		14,551	
Heating Operating Savings			$93
Fan Energy Usage	767 kW		
Fan Operating Cost			($51)
Net Operating Savings			$1,118

Example 2

Location: Minneapolis, Minnesota

Summer Conditions:
Indoor air: 75°F, 50% RH
Maximum outdoor air: 88°Fdb, 74°Fwb
Supply air from wheel: 77.7°Fdb, 65.5°Fwb

Summer Ventilation Load:
Sensible: 30,888 Btuh
Total: 89,201 Btuh
Recovered energy: 70,631 Btuh (5.89 tons)

Winter Conditions:
Indoor air: 72°F, 40% RH
Minimum outdoor air: -11°Fdb, -12°Fwb
Supply air from wheel: 55.8°Fdb, 45.8°Fwb

Winter Ventilation Load:
Sensible: 197,208 Btuh
Total: 252,775 Btuh
Recovered energy: 190,745 Btuh

Overall Effectiveness: 75.5 to 79.2%

Net Annual Operating Savings: $1,740

Example 2 - Bin Energy Analysis Summary

Outdoor Air °Fwb	MCWB °Fwb	Annual Hours	Vent. Load MBtu	Recov. Load MBtu
92.5	72.48	51	3,879	3,072
87.5	70.62	150	8,908	7,056
82.5	68.14	227	8,869	7,025
77.5	66.02	291	6,628	5,250
72.5	62.76	333	0	0
67.5	58.84	203	-105	-83
62.5	53.64	201	-1,693	-1,341
57.5	50.14	226	-6,191	-4,904
52.5	45.69	174	-8,839	-7,001
47.5	41.91	212	-14,651	-11,605
42.5	36.91	244	-22,447	-17,780
37.5	33.12	296	-31,890	-25,259
32.5	29.57	296	-36,107	-28,600
27.5	24.69	190	-26,853	-21,270
22.5	19.97	141	-22,379	-17,726
17.5	15.27	170	-29,554	-23,409
12.5	10.67	105	-19,906	-15,767
7.5	5.43	81	-16,661	-13,197
2.5	0.42	106	-23,282	-18,441
-2.5	-5.88	34	-8,102	-6,417
-7.5	-10.85	11	-2,780	-2,202
-12.5	-16.5	7	-1,811	-1,435
-17.5	-21.0	3	-709	-561

-22.5	-25.0	1	-245	-194
TOTAL				
	Cooling	712	28,284	22,403
	Heating	2,476	274,201	217,191

Example 2 – Annual Economic Summary			
Supply Air, cfm	2,200		
Exhaust Air, cfm	2,000		
Air-Cond. Load Saved, MBtu		22,403	
Air-Cond. Operating Savings			$399
Heating Load Saved, MBtu		217,191	
Heating Operating Savings			$1,392
Fan Energy Usage	767 kW		
Fan Operating Cost			($51)
Net Operating Savings			$1,740

HVAC System Downsizing

In both examples above, the recovered energy is sufficient to permit downsizing the HVAC system. The designer must be aware that when operating with an energy recovery wheel, HVAC system downsizing is more than a benefit; it may also be a requirement. This is especially true for the air-conditioning system.

Consider a situation where the outdoor air load represents a significant portion of the total system load. Let us assume further that the designer is very conservative and does not want to rely on an operating energy wheel for cooling capacity. If the HVAC system is not downsized, and if the outdoor air load is 70 to 80% eliminated by an energy recovery wheel, the system may never be tasked near full capacity. At part-load conditions, the energy recovered may represent an even larger percentage of the total system load. This means that the refrigeration components may be forced into a condition where they are substantially unloaded or cycle off. Humidity control will then be lost and the building occupants' comfort will diminish. The importance of making design adjustment to account for this behavior is especially pertinent to large, built-up systems.

When operating with an energy recovery wheel, the HVAC system must be sized for the actual load conditions that it will experience, not the total load shared with the energy recovery wheel. Failure to downsize will result in an oversized HVAC system and inefficient operation.

Cross-Contamination

In most comfort-to-comfort applications, contamination of the supply air stream with exhaust air is not an issue. Carryover and leakage are the mechanisms that drive mixing between the supply and exhaust air streams in all energy wheels. Carryover happens as a result of wheel rotation. As the energy wheel rotates, air is entrained in the media and is carried over from one air stream to the next. Leakage happens because there is an inevitable static pressure difference between the ducts. Seals are placed between the ducts and around the energy wheel perimeter, but they are not completely effective. The combined effect is a transfer of about 3 to 5% of the flow rate.

The University of South Alabama School of Engineering performed a study that investigated the potential of desiccants to adsorb contaminants in the exhaust stream that could be carried over to the supply stream. Their finding was that water was the most strongly adsorbed molecule. The selective preference of desiccants to adsorb water molecules is so great that it prevents the co-adsorption of contaminant molecules (i.e., ammonia, carbon dioxide and hydrocarbons).

Since cross-contamination is typically less than 5% of the airflow in a balanced system, it is generally not an issue. This is still true even when the exhaust air is toilet exhaust. In comfort-to-comfort applications, exhaust stream leakage to the supply stream is not really contamination so much as air that never really left the space. In toilet exhaust applications, the exhaust stream is highly diluted. Five percent cross-contamination is not sufficient to carry over detectable odors.

For applications where cross-contamination may be an issue, energy wheels are available with purge sections to eliminate nearly all carry over.

However, the installed and operating cost of purge equipment is rarely justified. If contamination is a serious issue, another form of energy recovery, such as a runaround system, is a more appropriate application.

Controls

Energy wheel control is necessary to prevent overheating the supply air during the winter and times when cooling with an economizer system. Control is also necessary in very cold weather to prevent frost accumulation on the media. Two methods of energy transfer control are typically used with energy wheels: (1) supply air bypass control, and (2) variable-speed drives.

The amount of air allowed to pass through the wheel determines the supply air temperature. A supply air bypass control damper is used to blend air passing through the wheel with a side-stream flow of unconditioned outdoor air. The damper position is adjusted to regulate the mixed air temperature downstream of the wheel.

Up to a point, the energy transfer effectiveness of a rotary wheel increases with increasing wheel speed. At the optimum speed for an application, the wheel will transfer the maximum amount of energy. If the wheel speed is decreased under the same conditions, the amount of energy transfer will decrease.

Maintenance

The first impressions after examining an energy wheel is that it will make a very good filter. In truth, energy wheels require very little maintenance. Particulate accumulation is an issue, so it is common practice to filter both air streams before entering the energy wheel. Filtration is not a critical issue though because the nature of an energy wheel, in a counter-flow installation, is to be self-cleaning. For instance, dust, lint, and particulates in the outdoor air stream large enough to be caught on the leading edges of the media filaments are blown away as the wheel passes into the exhaust air stream and the flow direction is reversed. Smoke, oil aerosols, airborne grease particles and fumes are a greater source of problems than particulates. Fumes and very small particles can precipitate onto the filament surface. Over a period of time, the accumulation of a film on the filament surface will impede the moisture adsorption capability of the desiccant. Latent efficiency may diminish 20% or more over a period of one to three years if not cleaned.

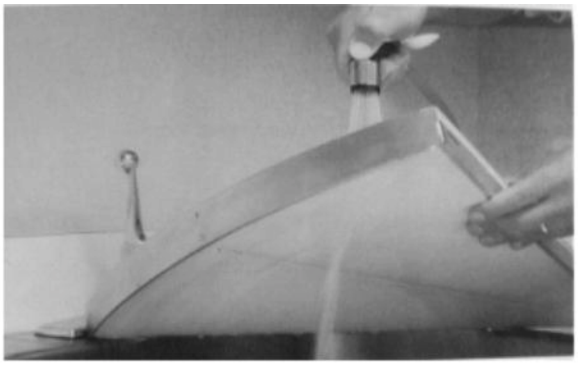


Figure 9. Rinsing an energy wheel media segment. Photo courtesy of Airexchange, Inc.

Media cleaning is an important component of regular energy wheel maintenance. The wheels or wheel segments should be removed every 6 to 12 months and cleaned with a non-acid based coil cleaner or alkali detergent solution. The wheel segments should be soaked in the cleaning solution then rinsed with clean water. Excess water should be allowed to drain before replacing the wheel segments. After returning the energy wheel to service, any moisture still captured between filaments is quickly evaporated. Polymer plastic media should never be cleaned with acid-based cleaners, aromatic solvents or water hotter than 170°F.

Energy Wheel Economics

Selection and application of an energy wheel should be based on the maximum cost-benefit, or lowest life cycle cost after considering energy savings and owning, operating, and maintenance costs. Accurate calculation of energy savings is the most complex issue in making an energy wheel assessment.

Air heating and cooling loads are time-dependent and cover a range of possible temperatures in most buildings. Time-of-use schedules vary, as do the hourly ventilation requirements and electric utility charges. Building heating applications will experience the peak heat recovery period when heat transfer control must be imposed to prevent frosting. In addition, most comfort-to-comfort applications have relatively small temperature differences between the exhaust and supply air streams. These small differences imply the need for more accurate energy modeling in order to maximize the cost-benefit or minimize life-cycle costs. In spite of the analysis complexity, payback periods of 6 to 36 months are not uncommon. Some applications, especially in hot, humid environments, have seen savings so great that paybacks were achieved within a few months.

Performance Ratings

ASHRAE *Standard* 84, Method of Testing Air-to-Air Heat Exchangers defines a uniform method of testing for obtaining performance data. It also specifies the data required, calculations to be used, reporting procedures, and test equipment to be used.

ARI *Standard* 1060, Rating Air-to-Air Energy Recovery Ventilation Equipment is an industry-established standard for rating air-to-air heat and energy exchangers for use in energy recovery ventilation equipment. Equipment must be tested in accordance with ASHRAE *Standard* 84, except where modified by ARI *Standard* 1060. ARI has also established *Certification Program* 1060 to verify ratings published by manufacturers.

Table 1 – Comparison of Air-to-Air Energy Recovery Devices

	Rotary Wheel	**Fixed Plate**	**Heat Pipe**	**Runaround Loop**	**Thermosiphon**
Airflow arrangement	Counter-flow Parallel-flow	Counter-flow Parallel-flow Cross-flow	Counter-flow Parallel-flow	Counter-flow Parallel-flow	Counter-flow Parallel-flow
Equipment size range, cfm	50 to 70,000	50 and higher	100 and higher	100 and higher	100 and higher
Type of heat transfer (typical effectiveness)	Sensible (50-80%) Total (55-85%)	Sensible (50-80%) Total (55-85%)	Sensible (45-65%)	Sensible (55-65%)	Sensible (40-60%)
Allowable face velocity	500 to 1,000 fpm	100 to 1,000 fpm	400 to 800 fpm	300 to 600 fpm	400 to 800 fpm
Typical design velocity	500 to 1,000 fpm	200 to 1,000 fpm	450 to 550 fpm	300 to 600 fpm	450 to 550 fpm
Pressure drop, in. wg.	0.25 to 1.0 in. wg.	0.02 to 1.8 in. wg.	0.4 to 2.0 in. wg.	0.4 to 2.0 in. wg.	0.4 to 2.0 in. wg.
Typical design pressure drop	0.25 to 1.0 in. wg.	0.10 to 1.5 in. wg.	0.4 to 2.0 in. wg.	0.4 to 2.0 in. wg.	0.4 to 2.0 in. wg.
Temperature range	-70°F to 200°F	-70°F to 1,500 °F	-40°F to 95°F	-50°F to 900°F	-40°F to 104°F
Advantages	• Latent (moisture mass) transfer • Compact large sizes • Low pressure drop	• No moving parts • Low pressure drop • Easily cleaned	• No moving parts except tilt • Fan location not critical • Allowable pressure differential up to 60 in. wg.	• Exhaust air stream can be separated from supply air • Fan location not critical	• No moving parts • Exhaust air stream can be separated from supply air • Fan location not critical
Limitations	• Cross-contamination possible • Cold climates may increase maintenance requirements	• Latent transfer available in units made of hygroscopic materials only	• Effectiveness limited by pressure drop and cost • Few suppliers	• To be highly effective requires accurate simulation model	• Effectiveness may be limited by pressure drop and cost • Few suppliers
Cross-leakage	1 to 10%	0 to 5%	0%	0%	0%
Heat rate control	Wheel speed control, or bypass dampers over full range	Bypass dampers and ducting	Tilt angle throttles down to 10% of maximum heat rate	Bypass valve, or pump speed control over full range	Control valve over full range

Source: ASHRAE. 2000. *HVAC Systems and Equipment Handbook*, Chapter 44. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

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